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ORIGINAL STUDY

Effect of the Natural Pozzolanic Basalt on High-strength Concrete

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Abstract

Concrete is important construction material in civil applications. Portland Cement (PC) is considered the essential component material to produce the concrete, especially in high-strength concrete. Around ranging from 5 to 7% of CO_2 was generated during PC production. Consequently, the concrete and PC production are change in the environment. So; it has become very important for the construction industry to focus on minimizing environmental pollution, energy consumption reduction. Several pozzolanic cementitious materials can be added as a fractional replacement of cement in concrete to reduce PC impact on environmental pollution. Pozzolanic materials include PC as one of its main components as well as natural or industrial by-products such as slag, silica fume, fly ash, etc. The major objective of this investigation is to study the effect of natural pozzolanic basalt on the properties of high-strength concrete in terms of lower shrinkage, low permeability, high modulus of elasticity, or high-strength using various percentages of basalt as replacement weights of PC by 5%, 10%, and 15% in concrete. Fresh concrete workability, setting times, compressive of concrete strength, splitting tensile strength, flexural strength, and concrete porosity percentage were investigated by testing samples of hardened concrete at various ages 7, 28, 56, and 90 days. According to the test results in this investigation, it can be concluded that the optimum quantity of basalt as a replacement for PC in high-concrete compressive strength mix is 10%, increasing in compressive strength, splitting, and flexural strength by 18.29%, 72.69%, and 15.23%, respectively, while decreasing in porosity by 18.26% when compared with a specimen without basalt.

Keywords: Basalt, Blended cement, High-strength concrete, Natural pozzolanic, Splitting tensile strength

1. Introduction

Basalt is considered one of the natural pozzolanic materials. Pozzolanic basalt is obtained by crushing boulders of pozzolana quarries, where a high amount of basalt dust gathered powders are a big problem related to environmental pollution. So, the using of basalt dust as admixtures in concrete can contribute to solving environmental problems. The capability of natural pozzolanic basalt materials to react with Ca $(OH)_2$, chemical formula of Calcium hydroxide, and to generate compounds that have cementitious properties when there is liquid water at normal temperatures made it a way to provide an economic production of concrete by saving costs and energy which consumed of cement manufacturing and improve the physical and chemical properties of concrete (Moawad et al., 2021). Natural pozzolan−silica fume combinations can improve the strength of mortars more than natural pozzolan or silica fume alone (Shannag, 2000). Pozzolanic activities and chemical properties of natural pozzolanas vary based on their source region.

The mechanical performance of Portland cement is affected directly when using blended basalt (Mendes et al., 2016). Using replacement cement materials in concrete is a reduction of the factors that decrease the concrete durability and enhancing its resistance to sulfate (Ghrici et al., 2007; Shui et al.,

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2010; Yeau and Kim, 2004). As well as; mineral additions are enhanced the compressive concrete strength by filling the pores and changing its diameter and distribution which leads to a decrease in concrete permeability and increase density consequently (Abdel-Latief et al., 2021). The commonly observed disadvantages of using natural pozzolanic basalt as replacement cement in concrete are decreasing in early ages of compressive concrete strength but increase with time long term (Khan and Alhozaimy, 2011), and to beat this disadvantage of low reactivity of basalt in high-strength concrete production of this investigation, concrete strengthening enhancer were added also to the concrete mix as a further chemical admixture for increasing of basalt reactions, especially at early ages of concrete (RagabYounis, Moawad). Basalt pastes specimens have better mechanical and physical properties than OPC paste specimens. So, natural pozzolanic basalt can be applied as a blended pozzolana material (El-Didamony et al., 2015). The elasticity modulus (young's modulus) of fresh concrete is affected by using basalt as a replacement for Portland cement in concrete with improving the concrete's compressive strength (Khan and Khan, 2017). Increasing the pozzolanic basalt powder fineness leads to slight influences on the hydration kinetics and also the mechanical properties of the mortar (Dobiszewska et al., 2019).

Many previous researches assessment and investigated the optimum level of pozzolanic basalt material as a fractional replacement of OPC in concrete, where; the addition of 8% of pozzolanic basalt powder replacement of cement in concrete leads to increase of both, flexural and compressive strength (Dobiszewska et al., 2019). While; the optimum level of pozzolanic basalt replacement cement in concrete was 15% (Dobiszewska and Beycioğlu, 2017). The increase of pozzolanic basalt powder content leads to an increase in shrinkage of mortar, and also a slight increase in mass loss (Lundgren, 2004; Uncik and Kmecova, 2013). The basalt powder is more often used as a fine aggregate (sand) replacement than a partial cement substitution (Yeau and Kim, 2004). Basalt powder as a replacement for the part of sand contributes to the improvement of physical and mechanical properties of mortars and concretes (Shui et al., 2010). Concrete shrinkage was increased with increasing in basalt replacement (Khan and Khan, 2017).

The research significant was studied the effect of using natural pozzolanic basalt as a supplementary cementing material for producing high-concrete compressive strength is the main objective of this investigation. As well as, determine the optimal ratio of natural pozzolanic basalt as a fractional replacement cement materials in high-concrete compressive strength.

2. Experimental procedure

The presented work aims to investigate and study the behavior of high-strength concrete using various ratios of natural pozzolanic basalt (5%, 10%, and 15%) as a fractional replacement of Portland cement (PC) in concrete with basalt reactivity ranging from 25% to 30%. The chemical, mechanical/physical properties of used natural pozzolanic basalt in this research were investigated also. The concrete mix proportions were used to produce high fresh concrete workability with a target concrete compressive strength of 60 MPa. The effect of natural pozzolanic basalt on mechanical properties, i.e., compressive concrete strength, tensile splitting concrete strength, and concrete bending strength, was recorded and investigated and for assessment of the optimum ratios of the natural pozzolanic basalt replacement material ratio level of cement in concrete were considered in this investigation related with the fresh concrete and hardened concrete performance.

3. Materials characteristics and concrete mix design

3.1. Ordinary portland cement

PC grade 42.5 Type I was used in present investigation. The chemical composition analysis of PC was conducted to get the composition and the results are listed in Table 1 (Abdellatief et al., 2023). Specific gravity and fineness of OPC are 3.15 and 2965 ± 50 cm^2/g respectively.

3.2. Silica fume

Silica fume was used as a blended cement materials by cement weight replacement in this investigation. Which it brought from the factories of the Egyptian ferroalloys local company. The chemical

Table 1. Chemical composition analysis of Portland ordinary cement.

Chemical composition	Concentration %
Lime saturation	0.890
Alumina modulus Al_2O_3	1.235
Insoluble residue	0.275
Magnesia MgO	0.92
Sulphuric anhydride (SO_3)	0.98
Loss in ignition (LOI)	0.95
Alkali	0.0031
Relative Humidity	67 ± 3

composition of the silica fume material used in this investigation were listed in Table 2. The specific surface area is about 30,000 m^2/kg. The density is about 550 kg/m^3. The mean grain size is 0.15 (μm). Specific gravity is 2.2 as per material data sheet.

3.3. Natural pozzolanic basalt

Natural pozzolanic basalt was brought from Wadi Hagool, Egypt, and used as a replacement material PC in the concrete mix. The collected of the three samples of natural basalt from the different locations in wadi Hagool area, after crushing by Jaw crusher ($<20\ mm$) were mixed together and quartered several times to get a representative technical sample. This technical sample in association with the above-mentioned materials (clays, limestone, sand and iron ore) with fixed ratios was used to prepare three different clinker mixes (Murray, 2006; Hewlett and Liska Lea's, 2004). The chemical analysis of natural pozzolanic basalt was investigated and mentioned in Table 3. Natural pozzolanic basalt was pulverized to pass through a sieve 90 μm.

3.4. Aggregates

Natural sand was used as a fine aggregate with maximum nominal size of 4 mm, while crushed stone dolomite was used as coarse aggregate by maximum nominal size ranging from 4.5 mm to 22 mm. And their physical properties were listed in Tables 4 and 5 respectively. Testing of sand and crushed stone grading were carried out according to the ESS 1109/2002 and given in Figs. 1 and 2.

3.5. Chemical super plasticizer admixture

To obtain high-concrete workability without increased water, Super plasticizer admixture viscocrete 20 HE was used in this investigation. The admixture following ASTM C 494 (Murray, 2006) type F with the listed properties:

Table 2. Analysis of Chemical Composition for silica fume.

Chemical composition analysis of Silica	Concentration %
Silicon dioxide (SiO_2)	91.51
Aluminum oxide (Al_2O_3)	1.12
Iron oxide (Fe)	1.48
Calcium oxide (CaO)	0.86
Magnesia MgO	0.77
Sulphuric anhydride (SO_3)	0.29
Potassium oxide (K_2O)	0.55
Sodium oxide (Na_2O)	1.3
Loss in ignition LOI	5.5

Table 3. Analysis of chemical composition for natural pozzolanic basalt powder.

Chemical composition analysis of basalt	Concentration %
Silicon dioxide (SiO_2)	44.79
Aluminum oxide (Al_2O_3)	10.16
Iron oxide (Fe)	12.87
Calcium oxide (CaO)	12.92
Magnesia MgO	8.89
Sulphuric anhydride (SO_3)	0.29
Potassium oxide (K_2O)	0.55
Sodium oxide (Na_2O)	2.3
Chloride (CL)	0.159
Loss in ignition LOI	3.8
SM (silica modulus)	1.79
AM (aluminum modulus)	0.68
Moisture	6.5

(1) Color/Appearance: Brown liquid.
(2) Density (at 20 °C) is 1.25 ± 0.005 kg/l.
(3) Compatible with all types of OPC.

3.6. Concrete strengthening enhancer admixture

The main parameter study in this investigation is ultimate concrete compressive strength, the concrete strengthening enhancer admixture was used in concrete mix as a ratio of cement weight by mixing with potable water of concrete mix to accelerate the reactivity of natural basalt with Calcium hydroxide in the early ages of concrete, strength enhancer admixture material was used in concrete mix.

(1) Appearance/Color: Brown liquid.
(2) Density (at 20 °C): 1.200 ± 0.005 kg/l.
(3) Compatible with all types of Portland ordinary cement.

4. Experimental methodology

4.1. Specimens details

4.1.1. Pastes and mortars mixtures

The investigation work is executed on mortars (specimens were consistent from cement, water and sand) and pastes (specimens were consistent from cement, and water without sand) cement specimens made without and with natural pozzolanic basalt

Table 4. Mechanical properties for fine aggregate.

Max. nominal size (mm)	Fineness modulus	specific Bulk gravity	Absorption capacity of water %	Organic impurities
4	2.62	2.66	0.98	null

Table 5. Mechanical properties for coarse aggregate.

Max. nominal size (mm)	dry unit weight (kg/m^3)	specific Bulk gravity	Absorption capacity of water %	Organic impurities
22	1580.1	2.67	0.61	null

powder used as partial replacement of PC weight. A strengthening enhancer of concrete chemical admixture for all cement pastes and mortars specimens was not added to study the mechanical properties of natural pozzolanic basalt reaction and reactivity. Where the using of the natural, and industrial waste and metakaolin can be used to lower environmental impact without compromising the mechanical performance of concrete (Abdellatief et al., 2023).

The influence of natural pozzolanic basalt powder content and its fineness on cement hydration was investigated by preparing pastes of cement without and with natural pozzolanic basalt in amount replacement of 0%, 5%, 10%, and 15% of cement weight. Mixtures of the cementitious paste were conducted with a fixed amount of water-to-blended cement ratio (w/s = 0.50). Pastes specimens containing natural pozzolanic basalt powder were named by using the abbreviations of P0, P5, P10, and P15, where the numbers indicate the percentage of Natural pozzolanic basalt replacement of cement in the pastes. And cement pastes mixture proportions were presented in Table 6.

Initial setting time (IST) and final setting time (FST) were conducted by using mortar specimens labeled as the abbreviations of M0, M5, M10, and M15 regarding to the natural pozzolanic basalt replacement of cement 0%, 5%, 10%, and 15% respectively.

4.1.2. Concrete mixtures and specimens fabrication

A 1:2.08:1.38 concrete mix ratio of OPC, crushed dolomite, and sand were used with a binder water-cement ratio of 0.28. Silica fume; physical admixture to produce high-concrete compressive strength, as a fraction of cement weight by 15%, super plasticizer viscocrete 20 HE, to enhance the workability, and concrete strengthening enhancer, to accelerate basalt reaction, chemical admixtures were used also in the concrete mix as a maximum dosage 2%, and (0,1—0,5 kg/t) respectively of the cement weight. Table 7 mentioned the proportions of the concrete mixes used in this study for various natural pozzolanic basalt replacements and blended by weight cement. In dry conditions, different amounts of natural pozzolanic basalt 5%, 10%, and 15% were replaced by the percentage weight of cement.

Concrete components materials were added by weight using a digital balance of 0.1 Kg sensitivity. Mixing is performed using a concrete drum mixer. First, crushed dolomite, sand, and PC were dry mixed for about 1 min until a homogeneous color

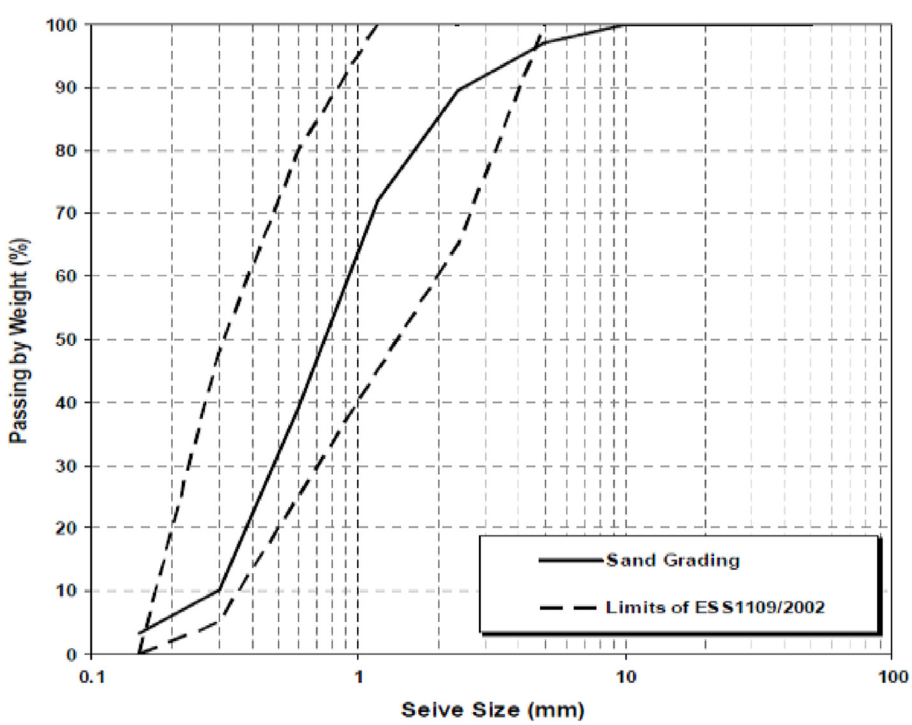

Fig. 1. Fine aggregate (sand) grading.

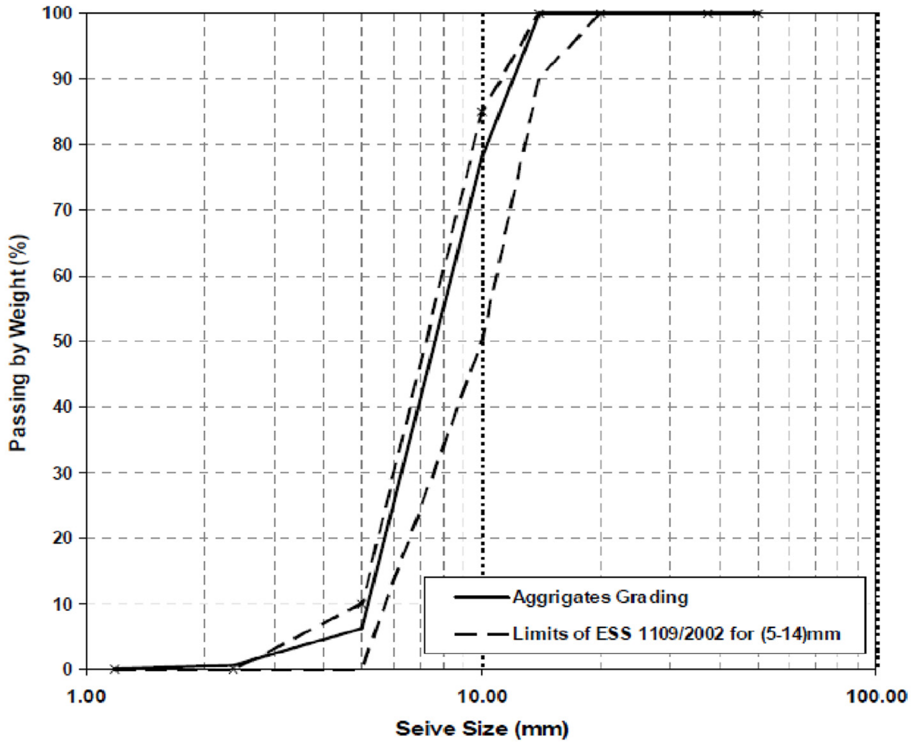

Fig. 2. Coarse aggregate (crushed stone) grading.

was observed. While mixing proceeded for 5 min in a drum mixer of the laboratory for all experimental concrete mixes, the water and chemical admixture were gradually added. Twelve standard specimens by cube steel molds of 150 mm side lengths were cast from each concrete mix for compressive concrete strength testing at various concrete ages 7 days, 28 days, 56 days, and 90 days. Four standard cylinder samples with diameter of 150 mm and height of 300 mm, were cast also from each concrete mix to determine the concrete split tensile strength at 28 and 90 days of age.

Two standard cubes of concrete samples with 100 mm a side length was poured from each concrete mix to determine the porosity and permeability of the concrete at a curing life of 28 days. Two beams of 500 mm span length, 100 mm width, and 100 mm height were cast from each concrete mix to examine and study the bending behavior strength of concrete at 28 days of age.

Table 6. Mixture proportions of cement paste.

Cement paste specimens	Cement	Basalt	Water/cement	(w/s) ratio
P0	5.00	0.00	0.5	0.5
P5	4.75	0.25	0.52	
P10	4.50	0.50	0.55	
P15	4.25	0.75	0.59	

After pouring the concrete, all samples were left in wet case and stored in the casting laboratory for 24 h. Samples were laid and processed at room temperature to the test day. Table 8 summarizes and illustrates the experimental Work plan for this investigation.

5. Results analysis

5.1. Properties of cement pastes and cement mortars

Chemical and physical characteristics such as compressive strength, setting times (initial and final), water of consistency, bulk density, and the total porosity were investigated for the hardened cement mortars and pastes specimens.

Table 7. Concert mix specimens proportion.

Specimens	CB0	CB5	CB10	CB15
% Basalt Replacement	0.00	5	10	15.00
OPC (kg/m3)	500	475	450	425
Basalt (kg/m^3)	0	25	50	75
Fine aggregate (kg/m3)	693	693	693	693
Coarse aggregate. (kg/m3)	1040	1040	1040	1040
Water (kg/m^3)	143.7	143.7	143.7	143.7
silica fume (kg/m^3)	75	75	75	75
Viscocrete 20 HE (kg/m^3)	10	10	10	10
Strengthening enhancer (kg/m^3)	2.5	2.5	2.5	2.5

Table 8. Experimental investigation work plan.

Study Parameters	Tested age (days)	No. of Specimens	Dimensions (mm)	Label specimens
Compressive strength	7	3-Cube	150 × 150 × 150	CB0 CB5 CB10 CB15
	28	3-Cube	150 × 150 × 150	
	56	3-Cube	150 × 150 × 150	
	90	3-Cube	150 × 150 × 150	
Splitting of concrete strength	28	2-Cylinder	(DIM. X Hight) ∅150 × 300	
	90	2-Cylinder	(DIM. X Hight) ∅150 × 300	
Flexural of concrete strength	28	1-Beam	(Width X Hight X Span) 100 × 100 × 500	
	90	1-Beam	(Width X Hight X Span) 100 × 100 × 500	
Porosity percentage	28	2- Cube	(Width X Hight X Span) 100 × 100 × 100	

5.2. Setting time and water of consistency effect

The water consistency, and setting times of the mortars made from PC and natural pozzolanic basalt are listed in Table 9 (EN 196, 2016a). Obviously, the partial substitution weight of OPC by natural pozzolanic basalt decreases the quantity of water demand for consistency in mortars specimens. Also, as the amount of natural pozzolanic basalt increases the consistency of water decreases and this is referring to the un-hydraulic properties of the natural pozzolanic basalt compared to OPC. The natural pozzolanic basalt has no or small pozzolanic activity. So; less water needed for cementitious compounds reaction. Consequently; the consistency of water decreases with increasing pozzolanic basalt content. Setting times for natural pozzolana basalt which filled mortar specimens was increased linearly with increasing of blended pozzolana basalt content in specimens (Moawad et al., 2021). This is mainly also due to the low reactivity hydraulic properties of the Natural pozzolanic basalt as comparing with OPC. Natural pozzolanic basalt does not take some extent in the initial hydration like OPC. As a result of OPC content decreases the setting times are elongated, i.e., the reduction of OPC with natural pozzolanic basalt leads to delay the reactions (Shui et al., 2010; Abdel-Latief et al., 2021).

Table 9. Water consistency, IST and FST of cement mortars with pozzolana basalt replacement 0%, 5%, 10%, and 15%.

Mortar specimen	Basalt %	Sample	St. Cons. %	IST min.	FST min.
M0	0%	1	29.6	150	190
		2	29.5	155	185
		3	29.8	150	195
M5	5%	1	26.5	150	240
		2	26	135	245
		3	25.5	140	246
M10	10%	1	27.2	160	260
		2	27.4	155	250
		3	27.2	145	245
M15	15%	1	29.2	170	265
		2	29	165	260
		3	29.2	160	265

The replacement of OPC with natural pozzolanic basalt mortars led to significant enhancement of fresh mortars workability where the diameter of flow was increased at increasing of natural pozzolanic basalt proportion in mortar. As natural pozzolanic basalt content increases in mortars, initial setting times increase slightly up to 6.45%, while increasing in the Final setting times up to 38.6% when compared to the cement mortar without natural pozzolanic basalt (El-Didamony et al., 2015).

5.3. Water content effect on cement paste/mortar specimens

Degree of hydration of cement pastes and cement mortars can be calculated by the amount of water demanded (Uncik and Kmecova, 2013). Consequently, the degree of pozzolanic blended cement hydration can be determinated by using the same previous phenomena. The water content of cement paste specimens are graphically plotted up to 90 days in Fig. 3. The mixed potable water content was increased gradually with time for all the cement pastes/mortars specimens based on progress heat of hydration. Generally, natural pozzolanic basalt in cement pastes specimens P5, P10, and P15 were demanded water lower than of cement pastes specimens without pozzolanic basalt. Also, as the basalt content increases the chemically combined potable water content decreases (Shannag, 2000; Uncik and Kmecova, 2013). This is mainly referring to the less pozzolanic activity, or nearly no pozzolanic material activity of basalt. Consequently, the

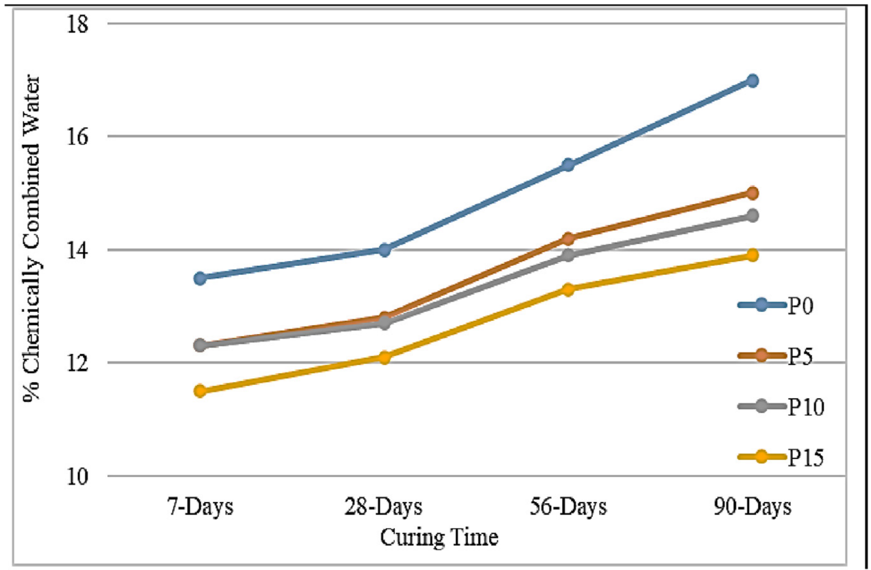

Fig. 3. Water demand of cement paste specimens.

amount of water mix content decreases with the decreasing of OPC which is the important factor of the pozzolanic cement pastes hydration during reactivity. The decrease in the mixed potable water content with the amount of substituted basalt is also based on the decrease in water of the cement paste specimens.

6. Fresh concrete

Slump tests for concrete specimens at time of 60 min for all concrete mixes without and with natural pozzolanic basalt as replacement cement were conducted and shown in Fig. 4. The results demonstrate the increase of the concrete slump when increasing in the natural pozzolanic basalt as a fraction replacement weight of cement where the concrete containing that 15% of natural pozzolanic basalt as partially replacement of cement was recorded maximum concrete slump during 60 min compared by residual concrete mixes in this investigation. Anyway, the natural pozzolanic concrete mixtures start and end with a higher slump in comparison to concrete with OPC according to the replacement ratio basalt of the cement, this is attributed to delay in basalt reaction with Ca $(OH)_2$, especially at the early ages (Khan and Alhozaimy, 2011).

7. Hardened concrete

7.1. Compressive strength

Concrete compressive strength is determined by conducting tests at various curing ages of hardened concrete specimens (7 days, 28 days, 54 days, and 90 days) as per specifications (Hewlett and Liska Lea's, 2004). The essential step toward understanding the rate of strong growth of concrete compressive strength is heat of hydration. The compressive strength was measured on concrete containing different ratios to replace natural pozzolanic basalt with cement in concrete as well as using of concrete strengthening enhancer admixture to accelerate the reaction of natural pozzolanic basalt. Because the natural basalt is siliceous or siliceous and aluminous materials and not have a cementing property although it can be reacted with Ca $(OH)_2$ in the presence of moisture at ordinary temperature to form compound possessing cementious properties with low activity. Therefore, the water demand decreased with the increase amount of natural pozzolanic basalt which is the main factor of the hydration of pozzolanic cement pastes, consequently the reaction was started later. Strengthening enhancer admixture can be improve both early and late age strength development in concrete by improving cement hydration and enhancing workability.

The concrete compressive strength was tested on three cubes specimens for each age at each type of concrete mix used to determine the high compressive concrete strength in this investigation study. The test results state the failure capacity load that the cube of concrete specimens can carry. And by dividing the load capacity failure by the corresponding loaded area. The high compressive concrete strength can be determined from formula (1) mentioned below.

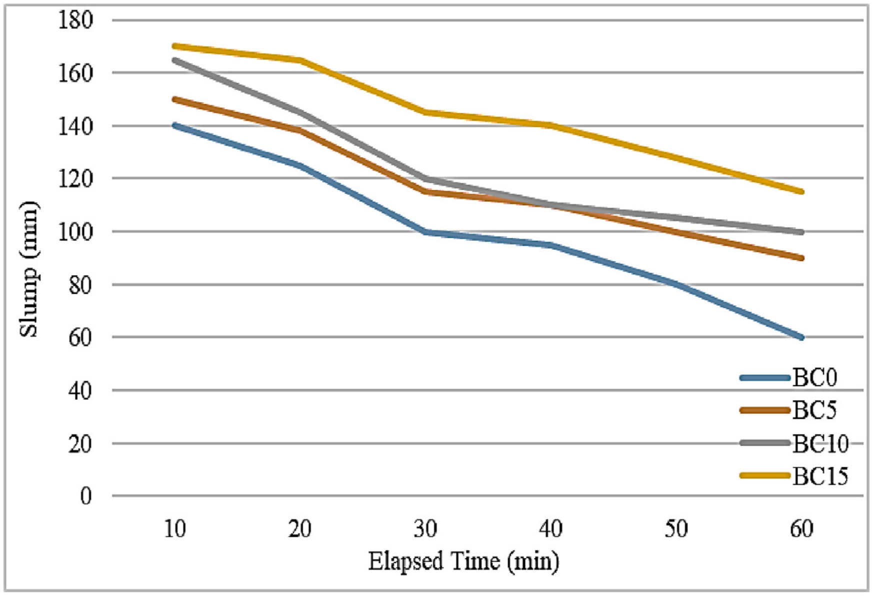

Fig. 4. Effect of natural pozzolanic material on the slump loss of concrete.

$$\text{Compressive strength (MPa)} = \frac{P_f}{A_L} \quad (1)$$

where; (P_f) failure load, and (A_L) is cross-sectional of the loaded area.

Table 10 listed all the results of compressive strength of concrete specimens and are graphically plotted in Fig. 5.

The cementitious compounds were generated during the hydration process which is the main binder of OPC paste in concrete. It begins to form in the early beginning stages of contributing to hydration of the cement and it progressively densifies as cement sets, so cementitious materials can be considered that it is the primary source of cement contributing to pastes compressive strength, and although the reaction of natural pozzolanic basalt with Calcium hydroxide to generate compounds have cementitious properties but this reaction occurring slowly at early ages of concrete as shown in cement mortars and pastes test results.

Compressive mortar cement strength concerning replacement of basalt powder without addition, strengthening enhancer admixture, shown that the additive of natural pozzolana basalt as a PC replacement causes the decrease of the compressive mortar cement strength in early curing times where the most visible decrease is observed in the case of mortar with 15% replacement of PC by natural pozzolanic basalt powder, i.e., 22.23%, 8.78% at curing concrete ages 28, and 90 days respectively when compared with cement mortar without blended natural pozzolanic basalt. So; the concrete strengthening enhancer chemical admixture was used in high-strength concrete mix, where the tests results of concrete cubes specimens show that increasing in concrete compressive strength at various ages curing starts from 7days up to 90 days compared with control concrete specimen BC0 as mentioned previous in Table 10, the results shows that the effect of concrete strengthening enhancer and its roles to increase the concrete compressive strength especially at early ages of concrete, so that the compressive concrete strength values are approximately the same if not equal at the age of 7 days for concrete mixes has 5%, and 10% of natural pozzolanic basalt with negative effect for concrete mix has 15% natural pozzolanic basalt, while increasing observed in compressive concrete strength specimens BC5, BC10, by 3.32%, and 18.29% with continuation the negative effect for concrete specimen BC15 by 5.00% reduction at age 28 days when compared with control concrete specimen BC0.

The concrete mix of specimen BC10, which has a natural pozzolanic basalt 10% of OPC replacement,

Table 10. Compressive strength of concrete specimens.

Specimen ID	% Natural pozzolanic basalt	Average High Compressive Concrete strength (MPa)			
		7 days	28 days	56 days	90 days
CB0	0%	46.2	62.3	68.1	69.6
CB5	5%	46.3	64.4	72.0	73.0
CB10	10%	46.7	73.7	82.9	88.5
CB15	15%	44.4	59.2	70.0	72.0

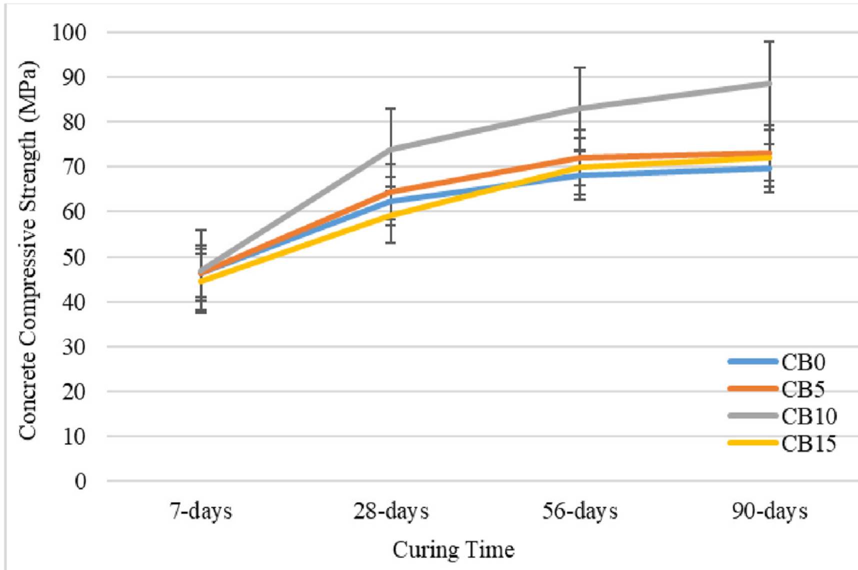

Fig. 5. High-concrete compressive strength.

was given maximum compressive strength during the long-life of 56 days and 90 days by 21.73% and 27.23%, respectively, when compared with the control concrete specimen BC0. While the negative effect decreased the compressive strength of specimen BC15 at 7 days and 28 days by 3.95% and 5.00%, respectively, a slightly positive effect was observed at long-life at 56 days and 90 days by 2.81% and 3.40%, respectively, in comparison to the control specimen CB0.

The conducted test result of the compressive concrete strength using natural pozzolanic basalt as a partially replacement OPC in mix of concrete demonstrated that the increase in the percentage of natural pozzolanic basalt in blended cement over 15% was not obtained a good result in high-strength concrete in the early age and long-life age, although the target compressive strength of concrete was achieved at age 28 days for CB15. Where decreasing in compressive strength for CB15 by 4.98%, 19.68%, 5.53%, and 18.72% for tested ages 7, 28, 56, and 90 days respectively when compared with concrete mix specimen CB10. While 5% of natural pozzolanic basalt as partially replacement of ordinary cement in mix concrete was given a close result with concrete mix without basalt. But 10% of natural pozzolanic basalt as partially blended of ordinary cement in mixed concrete was given a good results and performance in high-strength concrete. So, the optimum partially percentage of replacement natural pozzolanic basalt is 10% due to high-strength concrete.

7.2. Splitting strength

The strength of concrete against tensile stresses was determinate by splitting of concrete cylinders after 28 and 90 days (EN 196, 2016a). Standard cylinder molds were used as shown in Fig. 6. Compression load was applied on the longitudinal side of concrete specimens to induce transverse tension, it creates tensile stresses as illustrated in Fig. 7, and relatively high compressive stresses on the cylinder. When the cylinder concrete is given a

Fig. 6. Concrete cylinder Specimens.

Fig. 7. Splitting tensile test samples.

compression load along the solid plate kept parallel on either side of the cylinder concrete, the major tensile stress will be created along its diameter, and can be given and calculated by the formula of (2) (EN 196, 2016a) as following mentioned:

$$f_{ct=\frac{2f}{\pi dl}}\left(\frac{N}{mm^2}\right) \quad (2)$$

where; (f) is applied compression force over the longitudinal of cylinder length, (d) the diameter of concrete specimen cylinder, and (l) the length of cylinder specimen.

A total Sixteen of concrete cylinder specimens were conducted and tested of various proportions of natural pozzolanic basalt as a partial replacement of OPC in concrete mixes specimens after curing ages 28 and 90 days. Test results of the specimens as represented in Fig. 8. Two-cylinder specimens were tested at each curing age, and the average values was monitored and recorded in this investigation.

When natural pozzolanic basalt is used as a blended cement in high-strength concrete mixes, the splitting concrete tensile strength increases by up to 72.69%, and 75.77% at the ages of 28 and 90 days respectively, in concrete mix specimen CB10 when compared with concrete mix specimen CB0. This is due to the fractional replacement of Portland cement in the concrete mix with natural pozzolanic basalt material, which strengthens the interfacial transition zone. And it can be observed that the increase in the percentage of natural pozzolanic basalt in the blended Portland cement over 15% was not shows the highest results of the splitting concrete tensile strength where it can be observed that increase in tensile concrete strength of CB15 by 163.80%, and 65.83% at ages 28 and 90 days respectively when compared with CB0. While the concrete mix specimen CB5 gave the lowest concrete splitting strength by 53.65%, and 54.65% at ages 28 and 90 days respectively when compared with concrete mix specimen CB0. So, the optimum partial percentage of replacement natural pozzolanic basalt is 10% due to the highest values of splitting concrete tensile strength.

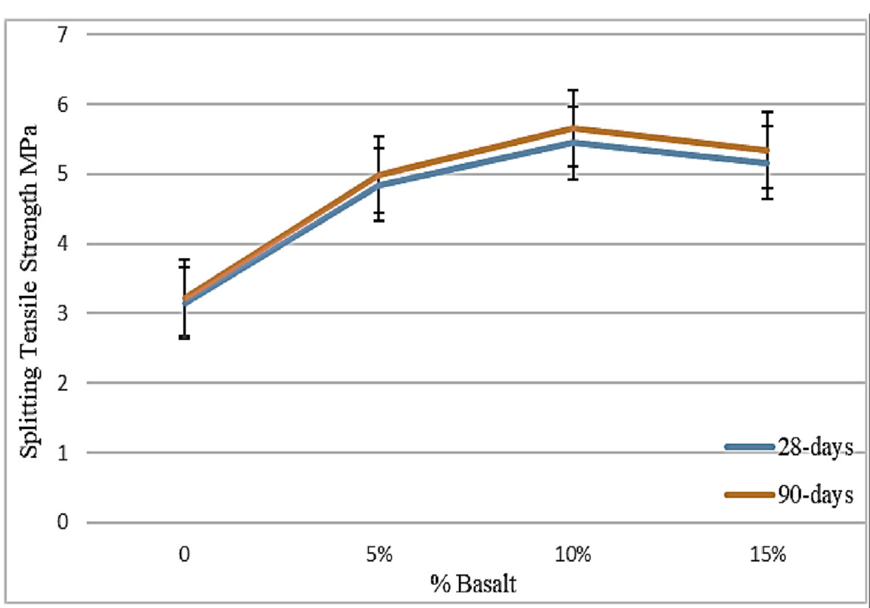

Fig. 8. Splitting concrete strength.

Fig. 9. Bending test machine.

7.3. Flexural bending strength

Eight Concrete beam specimens were fabricated by a different percentage of natural pozzolanic basalt as a partial replacement of cement as per specified in this investigation. Each concrete beam specimen was tested under flexural stresses (EN 196, 2016a). Which were performed in two loading points system as shown in Fig. 9. Two concrete beams were tested for each concrete mix BC0, BC5, BC10, and BC15 after a curing age of 28 days.

And the flexural strength can be calculated by the formula as in (3) as mentioned below according to BS EN 12390–5:2009:

$$f_{cf} = \frac{FL}{d_1 d_2^2} \text{ (MPa)} \tag{3}$$

where; f_{cf} = flexural strength (MPa), F = is the failure load (N), L = is the clear distance between the supporting rollers (mm), d_1, d_2 = are the lsateral dimensions of the specimens (mm).

The change in the flexural bending strength with respect to various percentages of natural pozzolanic basalt was presented in Fig. 10, which illustrated that the maximum flexural tensile strength was reached corresponding to 10% addition of natural pozzolanic basalt replacement of OPC in concrete.

The addition of natural pozzolanic basalt positively affects the flexural of high-strength concrete. The flexural bending strength of almost all examined concrete specimens made with addition of natural pozzolanic basalt powder is higher up to 15.23% and 12.59% for CB10, and CB15; respectively or is close to the control concrete (CB0) made without basalt.

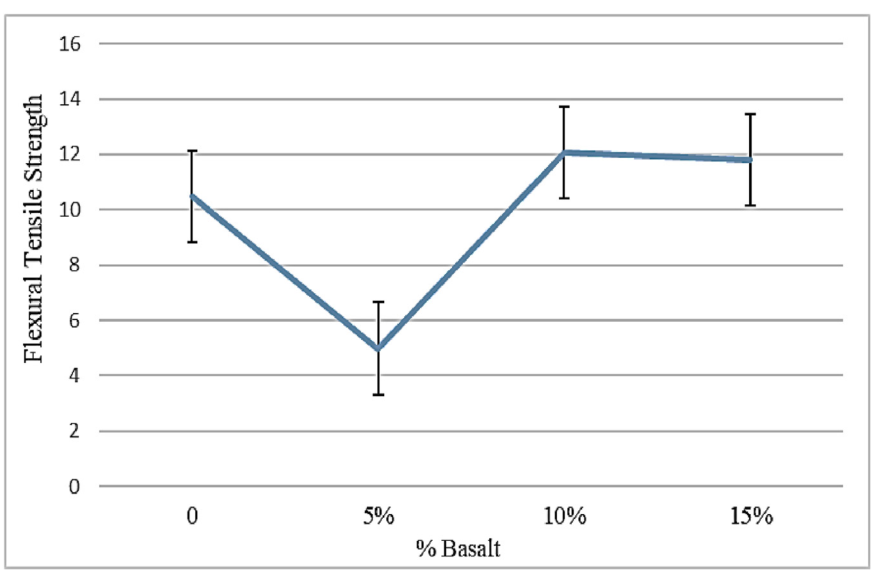

Fig. 10. Flexural strength of concrete specimens.

This phenomenon may be referred to the effect of strengthening concrete enhancer as a chemical admixture on natural basalt particles in the early hydration, which affects the early strength and pozzolanic activity of the basalt. And this is may be attributed to the fineness of the basalt particles.

7.4. Porosity

Porosity is a major factor in the concrete compressive strength. Where the decreasing in the porosity percentage lead to increasing in compressive strength of concrete. Concrete porosity percentage was calculated in this investigation by mass difference ratio divided by the concrete volume and can be given by formula (4) (Shannag, 2000; Khan and Alhozaimy, 2011; RagabYounis, Moawad; Standard Specification for Chemical) below:

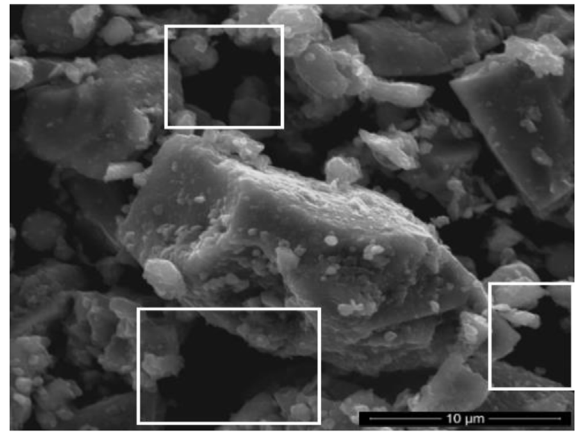

Fig. 12. SEM analysis of BC0.

$$\text{Porosity} = \left(\frac{\text{mass of concrete submerged} - \text{the mass of concrete dried}}{\text{Total Volume}}\right) \text{x100} \tag{4}$$

Porosity percentage of concrete mix specimens as shown in Fig. 11, and it was observed that the porosity decreased as the percentage of natural pozzolanic basalt increased up to 18.26%, 25.64%, and 34.56% at ages 28, 56, and 90 days respectively for specimen CB15 when compared with specimen without basalt CB0; this is mainly due to the continuous hydration of the cement forming hydration products and the basalt particles which is finer than of cement particles were precipitated in the open pores of the cement pastes. And this leads to the decrease of total porosity. Which this phenomenon was affected on the concrete strength. The slightly decreasing in the concrete porosity at

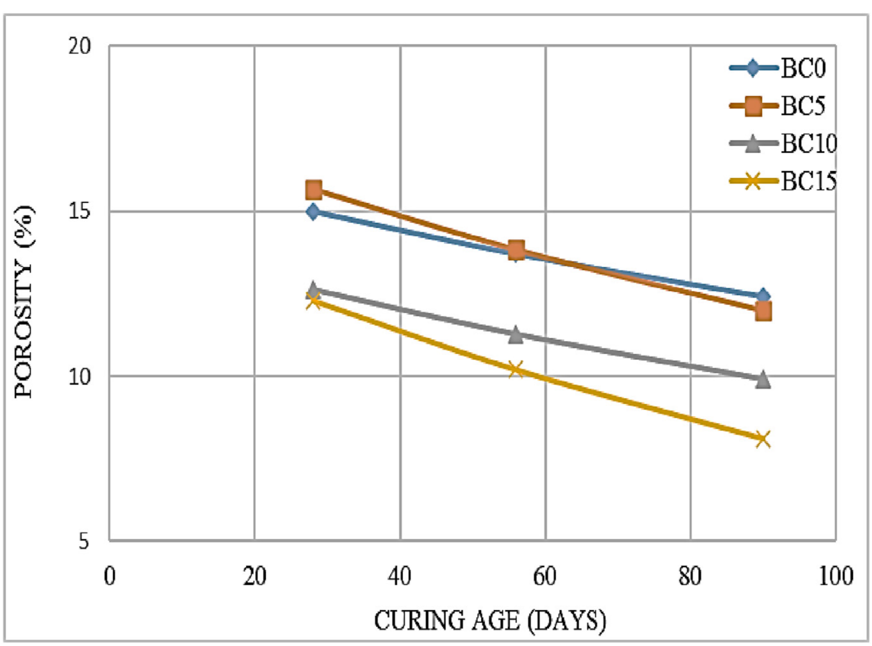

Fig. 11. Porosity percentage of concrete specimens up to 90 days.

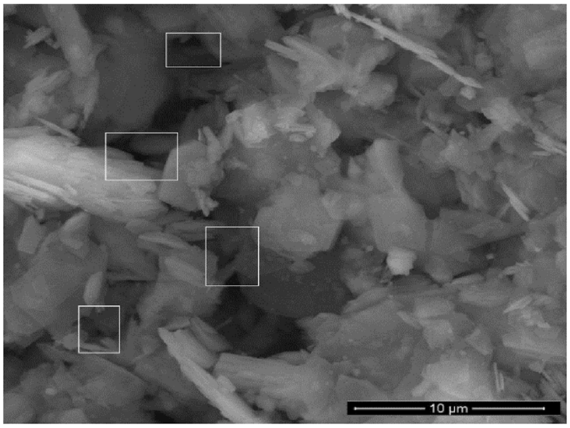

Fig. 13. SEM analysis of BC5.

90 days compared with 28 days (Moawad et al., 2021).

8. SEM analysis

The microstructures of the concrete specimens BC0, BC5, BC10, and BC15 were evaluated using the scanning electron microscope (SEM) as shown in Figs. 12–15.

The porosities were marked by white squares in figures. As can be seen, minor porosities are evident for natural pozzolanic basalt while large pores in Portland cement due to the high level of microstructure formation. Accordingly, the use of natural pozzolanic basalt as a blended material with PC in high-strength concrete was given a minor porosity percentage, especially when using of basalt ratio of 10%, which was recorded as the lowest pore in the concrete. While a large pore was observed in concrete specimen BC0 without using basalt. Consequently, both good effect in the chemical composition of the natural pozzolanic basalt and improving of the pores formation in concrete due to the basalt particles which is finer than of the cement particles which filled the pores between the cement particles.

9. XRD analysis

The influence of the curing time of concrete specimens until 90 days on the characteristics of hydration Pozzolanic mixed OPC containing 0%, 5%, 10%, and 15% weight of basalt can be realized from XRD patterns in Figs. 16–19.

The XRD pattern of basalt is shown in Figs. 16–19 the pattern indicates that it is natural pozzolanic basalt and composed mainly of the calcia-soda plagioclase feldspar mineral albite and the calcic pyroxene mineral augite.

It is clear that the characteristic peak of CSH increases, while the peaks of portlandite (CH) decrease with curing time. Typically, this is due to the pozzolanic response of the basalt percentage with the liberated lime, forming extra amounts of CSH. The rate of basalt pozzolanic reaction with lime grows with time. In this manner, the rate of lime utilization surpasses the rate of its generation. The behavior of CH peaks is in agreement with the results of chemically determined free lime. Moreover, the XRD patterns act in a $CaCO_3$ peak that increments with curing age, due to the increment of portlandite, which is accessible for carbonation with air CO_2 (RagabYounis, Moawad).

Hardened of concrete specimens have 15% natural pozzolanic basalt BC15, the XRD patterns after 28 days of hydration. The results seem to be the nearness of un-hydrous silicates (β-C2S and C3S), Calcium Hydroxide (CH), Calcite (CC), and Calcium

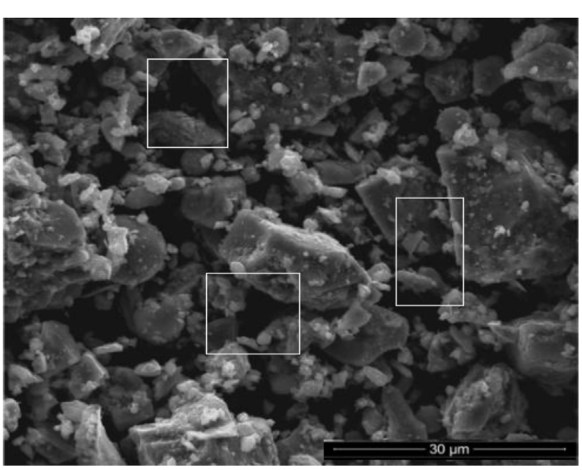

Fig. 14. SEM analysis of BC10.

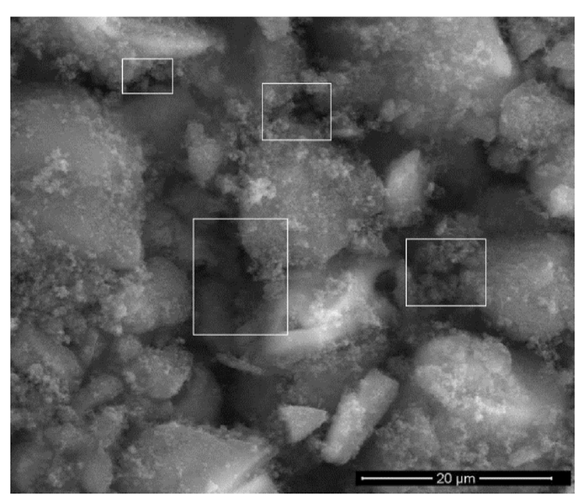

Fig. 15. SEM analysis of BC15.

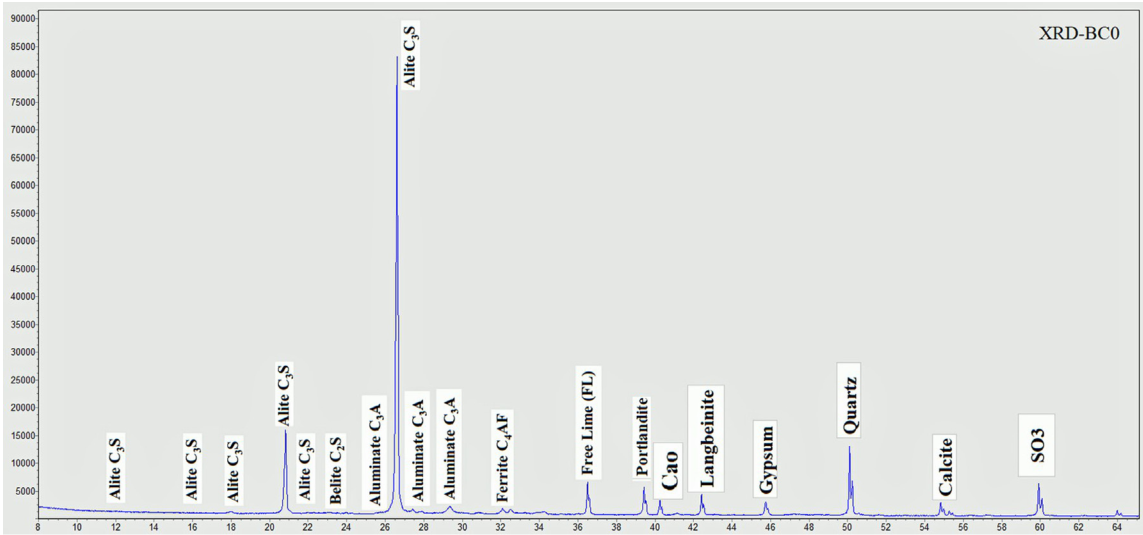

Fig. 16. Diffraction of X-ray of 0% natural basalt (2-Theta Scale).

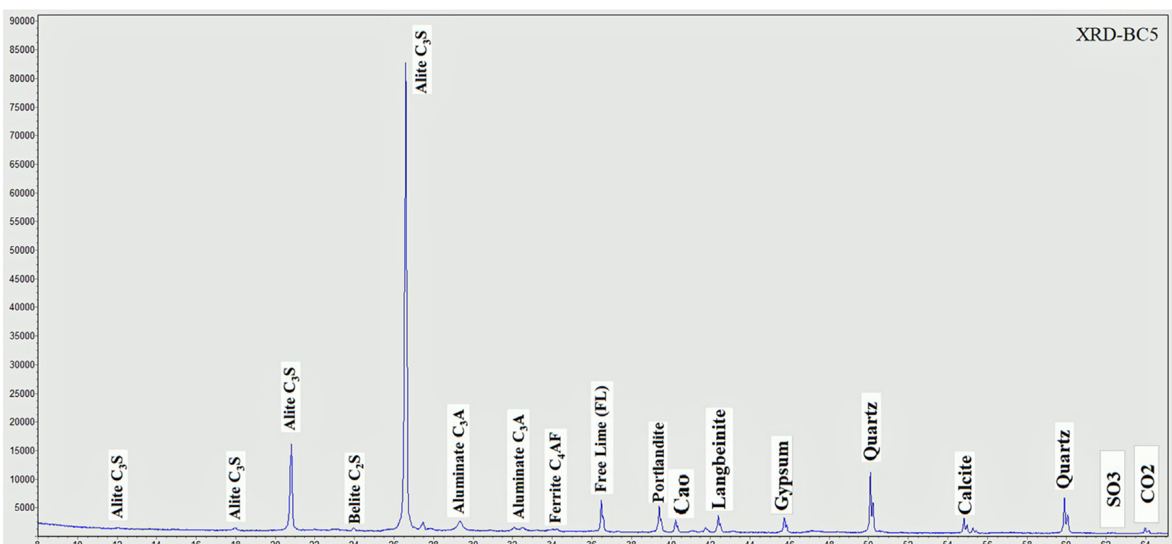

Fig. 17. Diffraction of X-ray of 5% natural basalt (2-Theta Scale).

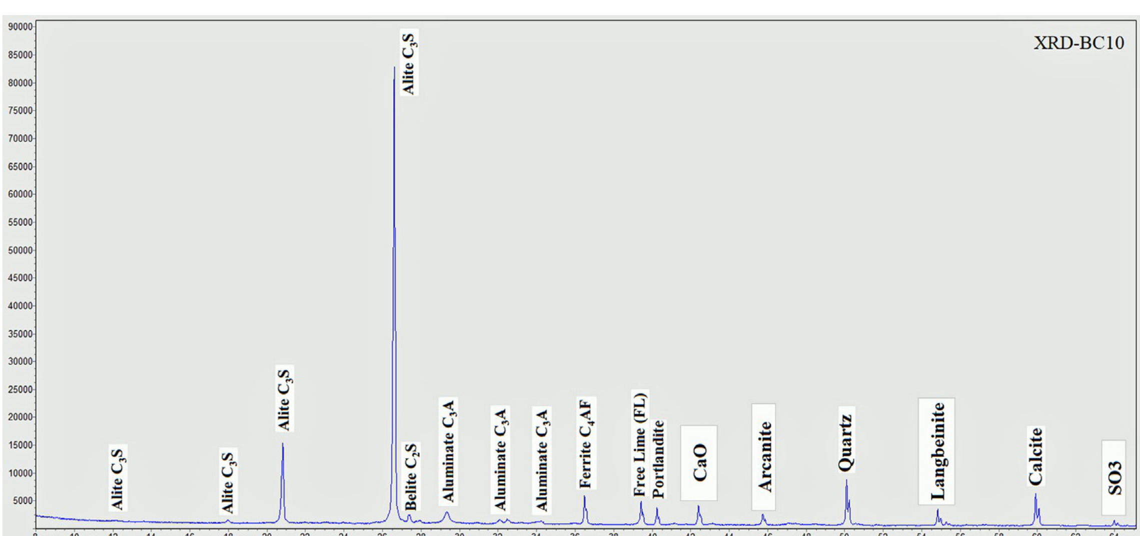

Fig. 18. Diffraction of X-ray of 10% natural basalt (2-Theta Scale).

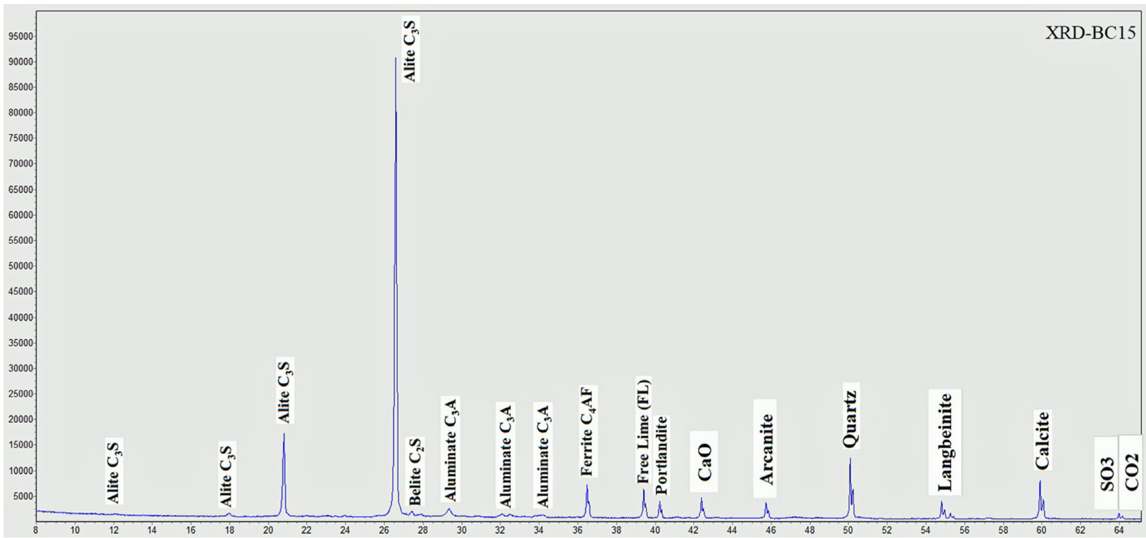

Fig. 19. Diffraction of X-ray of 15% natural basalt (2-Theta Scale).

Silicate Hydrate (CSH). The presence of 15% of basalt with Portland cement diminishes the amount of concrete specimens without basalt BC0. Moreover, the utilized basalt has low pozzolanic activity, particularly at early hydration ages. Hence, the intensity of CSH and CC peaks in BC0 is lower than the comparative peak in basalt blended cement specimens. Calcium hydroxide carries on in an inverse way to CSH. The peak of anhydrous silicate losses with the nearness of basalt, due to the reduction of clinker phases with 15% mass basalt. The intensity of the Portlandite peak is in agreement with that of a chemical inspection (EN 12390-3, 2001; BS EN 12390-6, 2009; BS EN 12390-5, 2009).

10. Conclusion

After experimental investigation work, the conclusions can be derived based on analysis and discussion of the test findings obtained in this study:

(1) basalt has low natural pozzolanic activity at early ages and increases with time.
(2) The water demand in concrete mixes including pozzolana basalt cement was lower than in concrete mixes containing PC with enhancement observation in the concrete workability.
(3) Using concrete strengthening enhancer admixture in the mix of concrete was solved that the low activity of the natural pozzolanic basalt at early ages.
(4) Pastes specimens made by natural basalt pozzolana have better mechanical and physical properties than paste specimens made by OPC. As well pozzolanic basalt had additional plasticizing properties, greatly improving the consistency of the pastes and mortars specimens.
(5) The optimum partial percentage of replacement natural pozzolanic basalt is 10% due high-strength concrete.
(6) The using of natural pozzolanic basalt cement in the concrete are decreasing porosity of concrete up to 34.56%.
(7) Basalt can be used as a cementitious material which can be increasing the concrete flexural strength up to 15.23%.
(8) Great enhancement in the concrete tensile strength by using basalt as a blended cement in the concrete mix up to 75.82% when compared with concrete mix without basalt.

Authors contribution

Mohamed Sayed Mohamed Moawad: Corresponding author. Design of concrete mix design proportions. Data collection and tools. Data analysis and interpretation. Supervision of experimental work. Drafting and Critical revision the article. **Abd EL-Rahman Ragab:** Chemical and physical analysis of raw materials. Analysis and drawing XRFD curve of basalt and cement. **Shimaa Younis:** Data collection and tools. Data analysis and interpretation. Supervision of experimental work.

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Conflicts of interest

There are no conflicts of interest.

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