Penerbit Akademia Baru

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: www.akademiabaru.com/araset.html
ISSN: 2462-1943

Effect of Partial Replacement of Fly Ash and Expanded Polystyrene waste on Properties of Geopolymer Concrete Bricks

Open Access

Jasim Mohammed Abed[1,*], Huda Saad Abed[1]

[1] Department of Building and Construction Technology Engineering, Engineering Technical College / Mosul, Northern Technical University, Iraq

ARTICLE INFO

Article history:
Received 21 October 2019
Received in revised form 13 December 2019
Accepted 15 December 2019
Available online 22 December 2019

ABSTRACT

The present experimental investigation was mainly focused on two major axes. The first one was the possibility of producing lightweight geopolymer concrete bricks using expanded polystyrene (EPS) waste and fly ash. The second axis was predicting the physical and mechanical properties of the geopolymer concrete bricks using non-destructive testing (NDT) techniques. (NDT) techniques viz Schmidt rebound hammer (RH), ultrasonic pulse velocity (UPV) and ((SonReb)) combined method. The NDT techniques were performed to compare the accuracy between the RH, UPV and ((SonReb)) method in predicting compressive strength of geopolymer concrete bricks. For these purposes, 25 different geopolymer concrete mixes were designed using EPS with different ratios (0, 10, 20, 30, 40 and 50%) as a partial replacement of coarse aggregates and fly ash (class F) by (0, 20, 40, 60 and 80%) as partial replacement of cement. A combination of sodium hydroxide (10M) and sodium silicate solution was used as an alkaline activator with a ratio of Na_2SiO_3/NaOH kept at 2.0, geopolymer bricks were designed with dimensions of 240 * 120 * 80 mm (6 bricks per mix). The physical and mechanical properties of the geopolymer concrete bricks were studied. Non-destructive testing techniques NDT has been used to predict correlation relationships between UPV, RH and compressive strength of geopolymer bricks. Different empirical formulas were proposed correlating the compressive strength of geopolymer concrete to RH, UPV and combined (SonReb) method. The validity of the empirical formulas was tested and compared with experimental relationships developed by previous researchers.

Keywords:
geopolymer concrete bricks; lightweight; physical properties; mechanical properties; nondestructive tests; combined (SonReb) method

1. Introduction

Clay brick industry is facing great challenges, production of good quality bricks requires the provision of high-quality raw materials. In addition to providing special types of kilns with high temperatures ranging from (1000-1400 °C). Also, the problems that occur in construction because of

* *Corresponding author.*
E-mail address: jasimabd@ntu.edu.iq (Jasim Mohammed Abed)

the phenomenon of Efflorescence due to the presence of alkali and some organic materials. Because of all these problems and others, the clay brick industry is slowly receding.

Concrete bricks are a good alternative for clay bricks in terms of mechanical properties and durability for long periods. But there are many negative aspects such as the heavyweight of concrete. Unfortunately, the most effective ingredient in concrete is Portland cement, which in turn causes the release of a huge amount of carbon dioxide during the manufacturing process. Where the production of one ton of Portland cement emits the equivalent of 640 kg of carbon dioxide gas [1]. The heavy-weight problem of concrete just can be solved by using lightweight materials such as Expanded Polystyrene (EPS) as a total or partial replacement of fine or coarse aggregates [2]. Expanded polystyrene (EPS) is used in the manufacture of pillows that help to absorb vibrations and shocks during the transfer of many ceramic and electrical materials and then become waste material. (EPS) material is not easy to decompose because of its chemical properties and light in weight, so it is not environmental friendly. So (EPS) can be incorporated with concrete to produce lightweight concrete by replacing it with coarse or fine aggregates, but with a significant reduction in concrete strength [3].

More than 7% of the CO_2 gas emitted into the atmosphere is the result of cement industry processes [4]. For this reason, Professor Joseph Davidovits in 1978, proposed the use of geopolymer technology, and he found that the polymerization process involves a substantially fast chemical reaction under the alkaline condition on Si-Al minerals that result in a 3D polymeric chain and ring structure consisting of Si-O-Al-O bonds. Geopolymers are three-dimensional networks of alumina-silicate particles formed by dissolution of materials containing reactive alumina and silica in alkaline activating solutions (sodium or sodium hydroxide) at a temperature below 100°C. When a source of Al-Si materials, such as fly ash mixed with an alkaline solution such as NaOH, with Na_2SiO_3, the geopolymer may be formed as -Si-O-Al-O- or –Si-O-Al-O-Si-O- or –Si-O-Al-O-Si-O-Si-O- [5].

Fly ash is defined as the powdered fuel ash extracted from fuel gases by cyclone separator or electrostatic precipitator. Fly ash does not contain any chemical binding properties, but when it reacts with sodium hydroxide (NaOH) during the process of hydration. it forms a (C-S-H) and in presence of SiO_2 and Al_2O_3 in fly ash, forms cementitious properties and thus gives considerable strength to concrete [6]. This study investigated the possibility of producing lightweight geopolymer concrete bricks, as well as studying their mechanical and physical properties in a contribution to find out an alternative to the clay bricks.

Most of the previous experimental researches [6], [11-14], and [19] on geopolymer investigated the behaviour of normal weight geopolymer concrete. This research deals with manufacturing of lightweight geopolymer concrete bricks and effect of replacing several percentage ratios of fly ash and expanded polystyrene (EPS) waste as partial replacement of cement and coarse aggregate respectively on the physical and mechanical properties. The experimental present data in this research are useful to predict some mechanical properties of geopolymer concrete bricks using non-destructive technique NDT. Also, the present research provides an additional way to improve the environment through the incorporating of expanded polystyrene waste in geopolymer concrete. And use it to reduce concrete products weight and trying to reduce the global demand of cement production through the use of fly ash in geopolymer concrete products.

2. Methodology

To achieve a better comparison of results, the main parts of the present research are illustrated in Figure 1. Mixing of concrete components (Portland cement, sand and gravel) with various ratios (0, 20, 40, 60 and 80%) of fly ash and adding ratios of expanded polystyrene waste as a partial replacement of coarse aggregate by (0, 10, 20, 30, 40, and 50%). Alkaline Activators were added in a ratio of 40% of fly ash. The concrete mixing process was carried out and the specimens were cast vertically in three layers, compacted manually 25 tamps per layer. The specimens were cured in an oven at 65°C for 5 hours, after that the specimens removed from the oven and immersed in water for 28 days at 24±2°C to allow concrete to cure and gain strength.

The procedures suggested by P. Pavithra *et al.* [11] and S.V. Patankar *et al.* [12] were followed to design twenty-five geopolymer concrete mixes designed with varying fly ash and expanded polystyrene percentage, including a non-polystyrene reference mix. The concrete slump test was fixed at 60mm for all mixes. For each mix, 6 bricks were cast with dimensions of 240 * 120 * 80 mm. Compressive strength, modulus of rupture, porosity, water absorption capacity, and nondestructive tests were tested for all specimens.

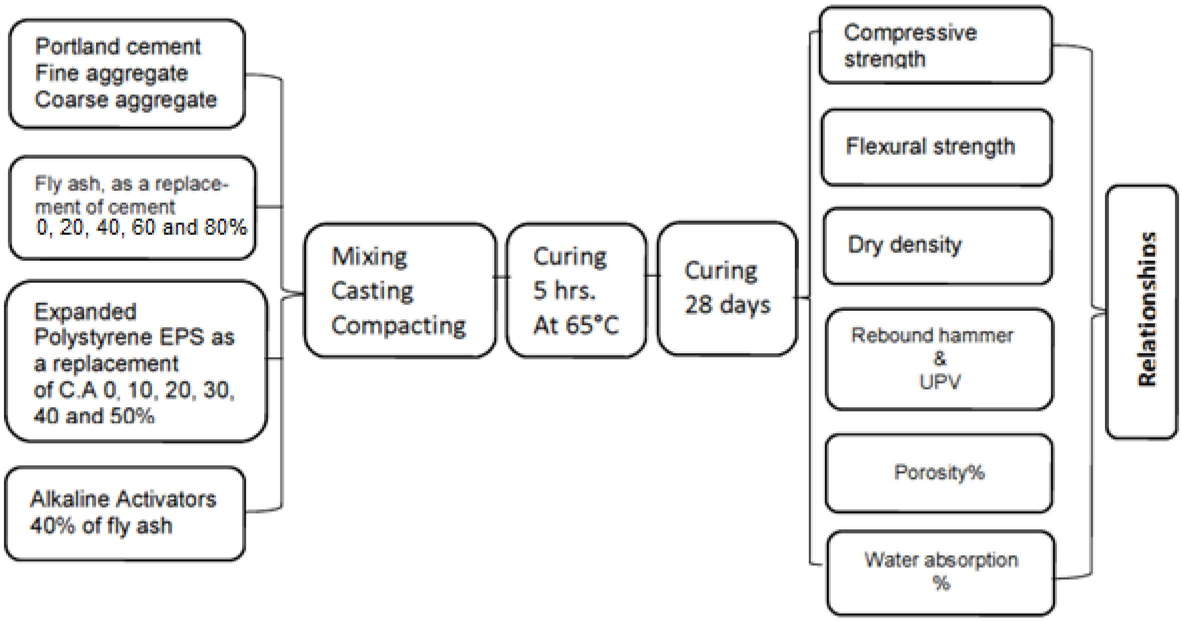

Fig. 1. Methodology of the experimental program

3. Experimental Program

3.1. *Cement:* Ordinary Portland cement produced by Badoshe cement factory in Mosul/Iraq was used, the chemical characteristics are showed in Table 1. Cement test results show that the cement conforms to the ASTM C150 [7].

3.2. *Fly ash:* Fine powder available in local markets with sacks weighing 25 kg, the used fly ash belongs to the ASTM C618 [8] Type F because the sum of the major oxides percent exceeds 70%. Table 1 shows the properties of used fly ash.

3.3. *Coarse aggregate:* clean river gravel conforming to the B.S 882:1992 [9] from the quarries of Mosul city was used in this research, with maximum aggregate size 12.5mm, fineness modulus, water absorption and specific gravity are 6.58, 0.72 and 2.72 respectively.

3.4. *Fine aggregate:* clean river sand conforming to the B.S 882:1992 from the quarries of Mosul city was used in present research with fineness modulus, water absorption and specific gravity are 3.1, 1.2 and 2.7 respectively.

Table 1
Characteristics of cement and Fly ash used in this study

Chemical Components	% by Weight of cement	% by weight of fly ash
SiO_2	22.4	55.3
AL_2O_3	5.17	22.4
Fe_2O_3	3.02	6.3
CaO	63.08	3.1
MgO	2.68	0.85
SO_3	2.13	0.1
In. SUL.R	0.71	-
L.O.I	0.81	0.76
Free Lime	0.91	-
L.S.F	95.45	-

3.5. *Expanded polystyrene (EPS):* Expanded Polystyrene was collected from local waste materials. Its specific gravity and maximum size were 0.015 and 7mm respectively.

3.6. *Alkaline Activators:* sodium hydroxide (NaOH) in white flake form and sodium silicate (Na_2SiO_3) in laboratory grade were used. Tables 2and Table 3 shows the chemical compositions of both sodium hydroxide and sodium silicate used in present research respectively. Concentrations of sodium hydroxide was fixed in all mixes at 10M.

Table 2
Characteristics of used sodium hydroxide

Chemical characteristics	%
Sodium hydroxide Min.	98
Carbonate	2.7
Chloride	0.015
Sulphate	0.05
Potassium	0.12
Silicate	0.05
Zinc	0.015

Table 3
Characteristics of used sodium silicate

Chemical characteristics	%
Na2O	17.28
SiO2	35.47
solid content	51.08
Water content	48.62

3.7. *Superplasticizer:* Confirming to the ASTM C 494/C 494M [10] a new superplasticizers type “F” a high-range water-reducing Naphthalene Sulphonate based superplasticizer was added to the mixture. The technical data are listed in Table 4.

Table 4
Physical properties of superplasticizer

Structure of the material	Naphthalene Sulphonate based
Color	Dark brown
Density	(1.15-1.21) Kg/liter
Chloride content %(EN480-10)	<0.1
Alkaline content % (EN480-12)	<10

3.8. Water: a clear tap water was used in mixing.

4. Mixing Process and Mix Proportions

400 grams of sodium hydroxide (NaOH) in white flakes form was dissolved in one litre of distilled water for a constant molarity 10M, the solution kept in the laboratory for 24 Hrs. A combination of NaOH and Na_2SiO_3 was prepared just one hour before mixing with fly ash. Coarse aggregate, sand and cement were mixed in a dry state. Then add the EPS (expanded polystyrene) and mixed again till be a homogeneous mix. The prepared mixture solution of alkaline activators (sodium hydroxide and sodium silicate) and fly ash add along with superplasticizer and extra water-based to gain a constant slump test value (60mm). Mix thoroughly 5 minutes till to be in a homogeneous state. As mentioned before the ratio of Alkaline activator to fly ash was fixed at 40% for all mixes. The use of this ratio was due to the works of Hardjito *et al.* [13] and Mustafa Al Bakri *et al.* [14] which considered an optimum ratio to produce best mechanical and physical properties at 28 days. The ratio of Na_2SiO_3/NaOH was kept at 2. However; Table 5 shows the mixes proportions of geopolymer concrete bricks.

Table 5
Mixes proportions of geopolymer concrete bricks

Mix	Cement kg/m^3	Fly ash kg/m^3	Sand kg/m^3	Gravel kg/m^3	EPS kg/m^3	SP % of powder	Alkaline activator 40% of fly ash		(W/GPB)
							NaOH	Na_2SiO_3	
M1	523	0	600	1150	0	1	0	0	----
M2	418.4	104.6	600	1150	0	1	6.973	13.946	0.22
M3	313.8	209.2	600	1150	0	1	13.946	27.893	0.22
M4	209.2	313.8	600	1150	0	1	20.92	41.84	0.22
M5	104.6	418.4	600	1150	0	1	27.893	55.786	0.22
M6	418.4	104.6	600	1035	0.634	1	6.973	13.946	0.22
M7	313.8	209.2	600	1035	0.634	1	13.946	27.893	0.22
M8	209.2	313.8	600	1035	0.634	1	20.92	41.84	0.22
M9	104.6	418.4	600	1035	0.634	1	27.893	55.786	0.22
M10	418.4	104.6	600	920	1.268	1	6.973	13.946	0.22
M11	313.8	209.2	600	920	1.268	1	13.946	27.893	0.22
M12	209.2	313.8	600	920	1.268	1	20.92	41.84	0.22
M13	104.6	418.4	600	920	1.268	1	27.893	55.786	0.22
M14	418.4	104.6	600	805	1.903	1	6.973	13.946	0.22
M15	313.8	209.2	600	805	1.903	1	13.946	27.893	0.22
M16	209.2	313.8	600	805	1.903	1	20.92	41.84	0.22
M17	104.6	418.4	600	805	1.903	1	27.893	55.786	0.22
M18	418.4	104.6	600	690	2.536	1	6.973	13.946	0.22
M19	313.8	209.2	600	690	2.536	1	13.946	27.893	0.22
M20	209.2	313.8	600	690	2.536	1	20.92	41.84	0.22
M21	104.6	418.4	600	690	2.536	1	27.893	55.786	0.22
M22	418.4	104.6	600	575	3.171	1	6.973	13.946	0.22
M23	313.8	209.2	600	575	3.171	1	13.946	27.893	0.22
M24	209.2	313.8	600	575	3.171	1	20.92	41.84	0.22
M25	104.6	418.4	600	575	3.171	1	27.893	55.786	0.22

5. Results and discussion

The experimental tests result of geopolymer concrete bricks are listed below in Table 6.

Table 6
Experimental tests results

EPS %	Mix	Compressive strength, MPa	Flexural strength, MPa	Water Absorption %	Apparent Porosity %	Dry density kg/m^3	UPV Km/sec	RN Hammer
0	M1	66.27	8.08	2.48	6.1	2467.014	5.08	56
0	M2	52.26	7.61	2.77	6.7	2426.215	4.8	46
	M3	40.20	6.74	3.50	8.5	2415.365	4.5	39
	M4	37.25	5.47	3.74	8.9	2391.927	4.42	37
	M5	34.23	5.24	4.15	9.8	2353.733	4.34	37
10	M6	49.30	6.87	3.48	7.8	2243.924	4.71	45
	M7	43.88	6.43	3.95	8.7	2200.087	4.58	41
	M8	34.11	5.39	4.47	9.7	2164.063	4.35	37
	M9	31.88	5.14	4.72	10.0	2126.302	4.3	32
20	M10	34.99	5.51	4.17	8.9	2122.830	4.37	35
	M11	32.59	5.35	4.81	10.0	2075.521	4.32	35
	M12	28.33	4.50	5.43	11.0	2021.267	4.22	31
	M13	26.25	4.41	6.13	12.1	1969.184	4.17	29
30	M14	28.89	4.57	4.98	9.5	1918.837	4.23	30
	M15	26.16	4.32	5.27	10.1	1910.156	4.17	29
	M16	21.87	4.01	6.49	12.1	1866.753	4.07	27
	M17	21.56	3.87	6.82	12.4	1820.313	4.06	26
40	M18	17.22	3.03	6.33	11.0	1733.941	3.96	24
	M19	15.34	2.55	6.72	11.5	1717.448	3.91	20
	M20	13.78	2.23	7.47	12.6	1691.406	3.88	17
	M21	12.55	1.92	7.76	13.0	1678.385	3.85	14
50	M22	15.32	2.69	8.50	14.0	1644.097	3.91	---
	M23	14.79	2.56	8.81	14.4	1634.983	3.9	---
	M24	12.23	1.81	10.86	17.2	1582.031	3.84	---
	M25	10.59	1.25	11.51	18.0	1561.198	3.8	---

5.1 Water absorption

The ASTM C67 [15] standard specification was followed to test water absorption capacity in geopolymer concrete bricks. The percentage of water absorption was calculated from Eq. 1, saturated and dry weights (*Ws* and *Wd*) of concrete bricks saturated in water for 24 hrs. After that dried in an oven for 24 hrs at 115°C.

$$\%Water\ Absorption = \frac{Ws-Wd}{Wd} * 100 \quad (1)$$

From Figure 2 it was observed that their significant increase in water absorption capacity of geopolymer concrete bricks with an increase in the per cent of EPS and fly ash incorporated in geopolymer concrete bricks. This is due to an increase in the percentage of pores generated by the replacement of EPS (0, 10, 20, 30, 40 and 50%) as a partial replacement of coarse aggregate. Such behaviour is fully compatible with Hernández-Zaragoza, J.B. [16]. The compressive strength of the geopolymer concrete bricks was negatively affected by increasing water absorption ratio for the same reason mentioned above.

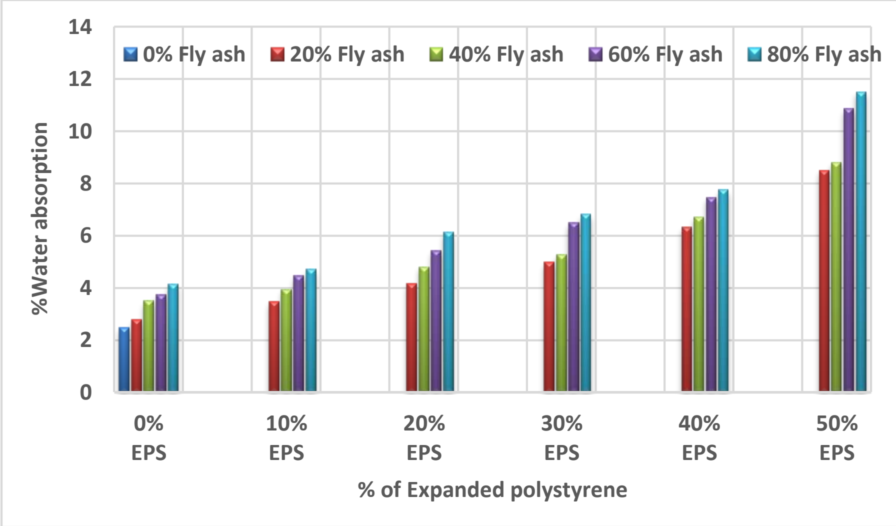

Fig. 2. water absorption% vs expanded polystyrene% of geopolymer concrete bricks

Figure 3 shows the relationship between the compressive strength of the geopolymer concrete and the water absorption ratio. It was observed that there was a significant reduction in compressive strength values by increasing the water absorption ratio in the various mixtures of geopolymer concrete bricks, this behaviour consistent to what was concluded by Thokchom *et al*. [17]. This behaviour is due to the increase in the ratio of EPS in concrete mixtures.

The experimental results can be useful to predict a relationship between compressive strength and water absorption ratio of concrete with an excellent correlation coefficient of more than 93% as plotted in Eq. 2 and Figure 3 and drawn below:

$$f_c = 203.94\, WA^{-1.231} \tag{2}$$

where: *fc* is compressive strength of geopolymer concrete bricks, MPa.
WA is water absorption, %.

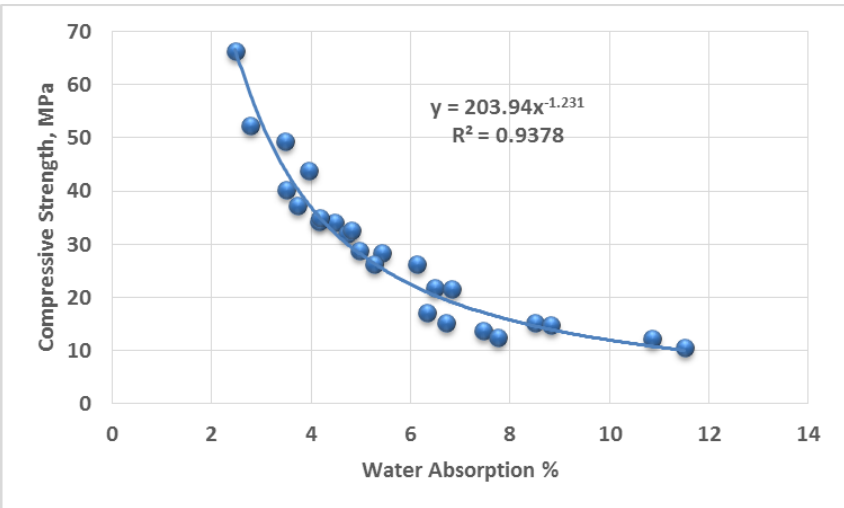

Fig.3. Compressive strength vs water absorption % of geopolymer concrete bricks.

5.2 Apparent porosity

The ASTM C140 [18] standard specification was followed in the porosity test of geopolymer concrete bricks. The specimens were completely immersed in water at 23±2°C for 24hrs. After, specimens were drained on paper towels for 10 minutes to remove excess water. The saturated suspended weights in water were recorded by a sensitive balance. The geopolymer bricks specimens were dried in the oven up to 115°C for 24 hrs. The porosity was determined from Eq. 3:

Apparent Porosity % = *(Ws-Wd)/(Ws-Wss) *100* (3)

where: *Ws* is saturated weight, gm
Wd is oven dry weight, gm
Wss is saturated-suspended weight, gm

The effect of porosity was not very different from the effect of water absorption ratio on compressive strength of geopolymer concrete bricks. It was noted from Figure 4 that there was a serious decrease in compressive strength by increasing the porosity in the structure of geopolymer concrete bricks containing different percentages of EPS. This behaviour is strongly compatible with Alsayed and Amjad [19].

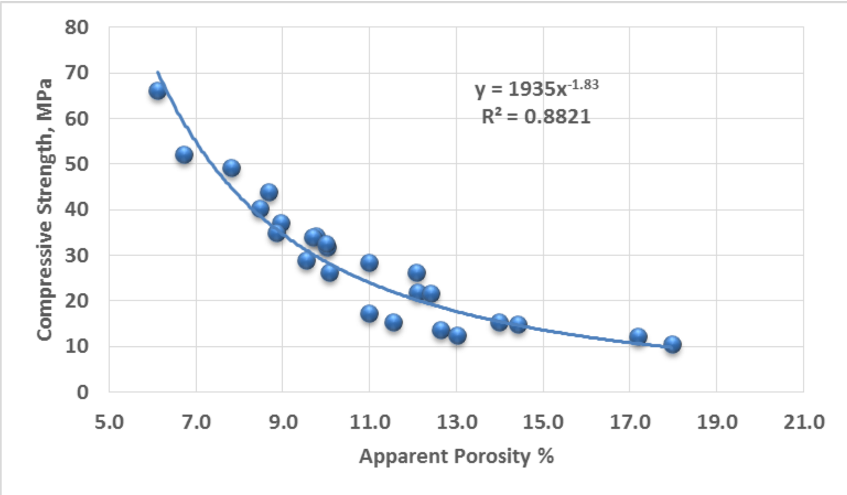

Fig. 4. Compressive strength vs apparent porosity % of geopolymer concrete bricks

The experimental results were used to establish a predictive exponential relationship between compressive strength and porosity ratio in geopolymer concrete bricks as reported in Eq. 4 below with a very good correlation coefficient R^2 about 88%:

$$f_c = 1935\ AP^{-1.8} \quad (4)$$

where: *fc* is compressive strength of geopolymer concrete bricks, MPa
AP is apparent porosity, %

The results seem to show a close correlation between water absorption and porosity ratio in geopolymer concrete bricks. When porosity increase, the size of the pores also increases. Thus, absorbed water also increases. Structure of the specimen becomes looser and weaker [20]. The experimental results used to develop a predictive exponential relationship between water absorption and porosity ratio of geopolymer concrete bricks as shown in Eq. 5 and plotted in Figure 5. With an excellent correlation coefficient exceeding 97%.

$$Water\ absorption, \% = 0.1509AP^{1.5139} \quad (5)$$

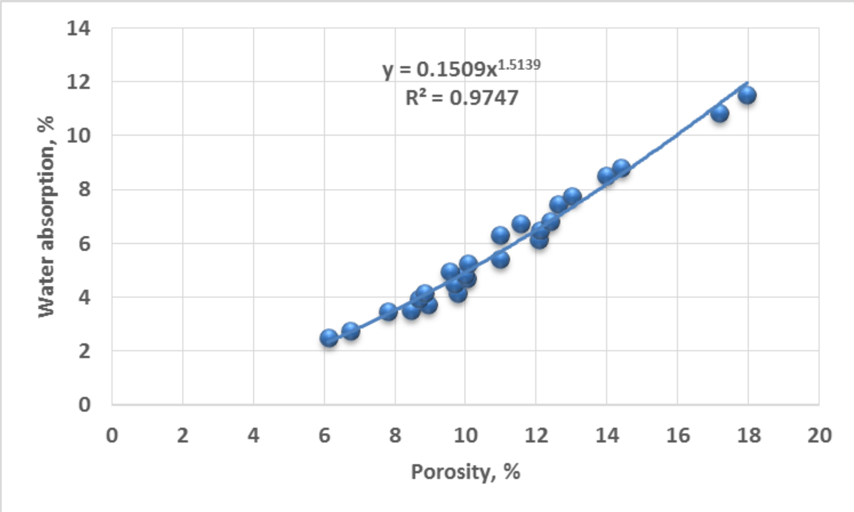

Fig. 5. Relationship between water absorption and apparent porosity of geopolymer concrete bricks

5.3 Dry density

The ASTM C140 [18] standard specification was followed to determine the dry density of geopolymer concrete bricks. Every set of geopolymer concrete bricks cured 28 days in water at 23±2°C. After specimens were taken out from the water and drained on paper towels to remove excess water until to turn in SSD (saturated surface dry) condition. Then the SSD weights of specimens were recorded. Then suspended weights in the water of specimens recorded by a sensitive electronic balance. The specimens dried in the oven up to 115°C for 24 hours until constant weight reached. However, dry density was calculated from Eq. 6:

$$Dry\ density = \frac{Wd}{Ws - Wss} * 1000 \quad (6)$$

where: *Ws* is saturated weight, kg
Wd is oven dry weight, kg
Wss is saturated-suspended weight, kg

Figure 6 shows the dry density of twenty-five different concrete mixes containing (0, 10, 20, 30, 40 and 50%) EPS and (0, 20, 40, 60 and 80%) fly ash. It was observed that there was significant reduction in dry density from 2467 kg/m^3 in control mix to 1561 kg/m^3 in mix containing (50% EPS as a partial replacement of coarse aggregate and 80% fly ash as a partial replacement of cement) with increasing of EPS replacement ratio and fly ash ratio. Even for a specific replacement ratio of EPS, it was observed that there slightly decrease in dry density with increasing in fly ash replacement ratio. However, the effect of increasing replacement ratio EPS as a partial replacement of coarse aggregate has more efficiency on reducing the dry density at a specific fly ash replacement ratio.

The reduction in dry density of the geopolymer concrete bricks due to the increased of EPS replacement ratio as a partial replacement of coarse aggregates or the increasing of fly ash replacement ratio as a partial replacement of cement was illustrated in Figure 7. The experimental results present in Figure 7 shows a serious reduction in compressive strength from 66 MPa to 10 MPa when dry density decreased from 2467 to 1561 kg/m^3 respectively.

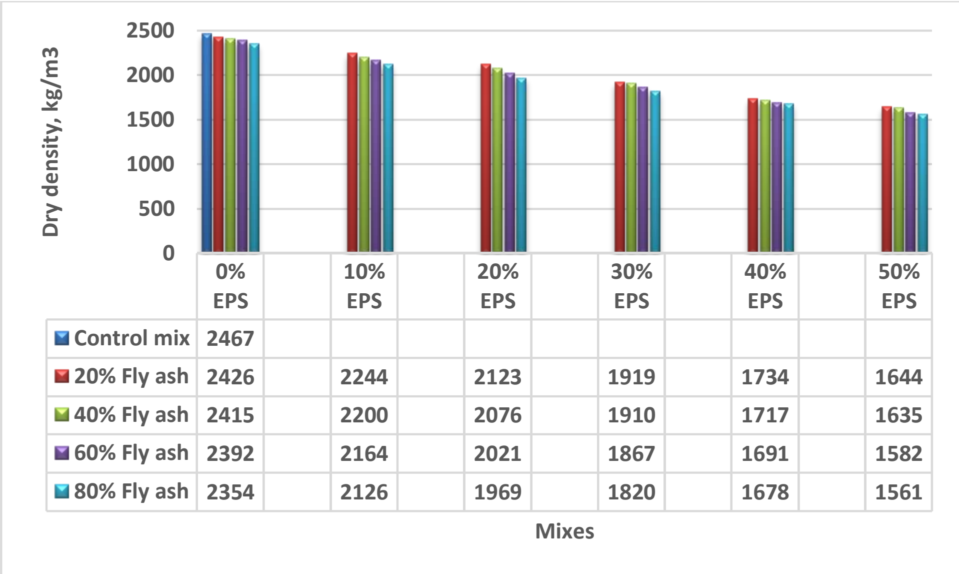

Fig. 6. Dry density of different geopolymer concrete mixes

The experimental results were used to develop an exponential relationship between compressive strength and dry density of the geopolymer concrete bricks with a correlation coefficient of about 90% as drawn in Eq. 7 and Figure 7:

$$f_c = 0.9747\, e^{0.0016Dry} \tag{7}$$

where: *fc* is compressive strength of geopolymer concrete bricks, MPa

Dry is dry density of geopolymer concrete bricks, kg/m^3

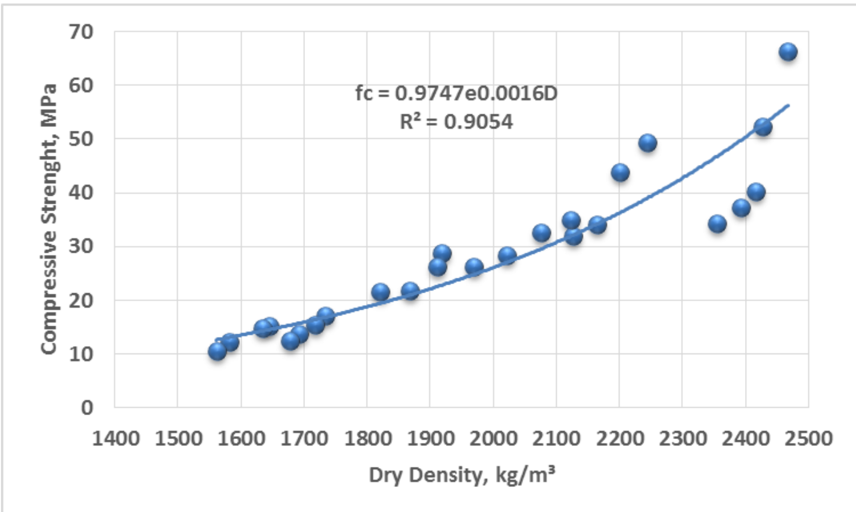

Fig.7. Compressive strength vs dry density of geopolymer concrete bricks

5.4 Flexural strength

A 2000kN capacity universal testing machine used in flexural strength test of geopolymer concrete bricks. The average of three specimens was reported. One-point load procedure was applied to determine the flexural strength of geopolymer concrete bricks with dimensions 240*120*80 mm. The flexural strength was calculated the Eq. 8 as below:

$$fr = \frac{3Pl}{2bd^2} \tag{8}$$

where: *P* : is maximum load, N
l : is effective specimen length, mm
b: is specimen width, mm
d: is specimen depth, mm

Figure 8 shows the flexural strength test procedure in geopolymer concrete bricks.

Fig. 8. Flexural strength test procedure

The results of the experimental tests were useful for the development of a logarithmic empirical formula between compressive strength and flexural strength of geopolymer concrete bricks. The empirical proposed formula is drawn in Eq. 9 and plotted in Figure 9:

$$fr = 3.6852\ln(fc) - 7.4952 \tag{9}$$

where: *fr* is flexural strength of geopolymer concrete bricks, MPa
fc is compressive strength of geopolymer concrete bricks, MPa

To ascertain the validity of the Eq. 9, it was compared with several of equations adopted in several international codes. Figure 10 shows the comparison of Eq. 9 results with ACI, BS-8110 and IS 456-2000 codes listed in Table 7.

Table 7
Recommended empirical relationships between Flexural and compressive strength [21]

Code	Country	Relationship
ACI	USA	$fr = 0.62\sqrt{fc}$
BS-8110	Britain	$fr = 0.60\sqrt{fc}$
IS:456-2000	India	$fr = 0.7\sqrt{fc}$

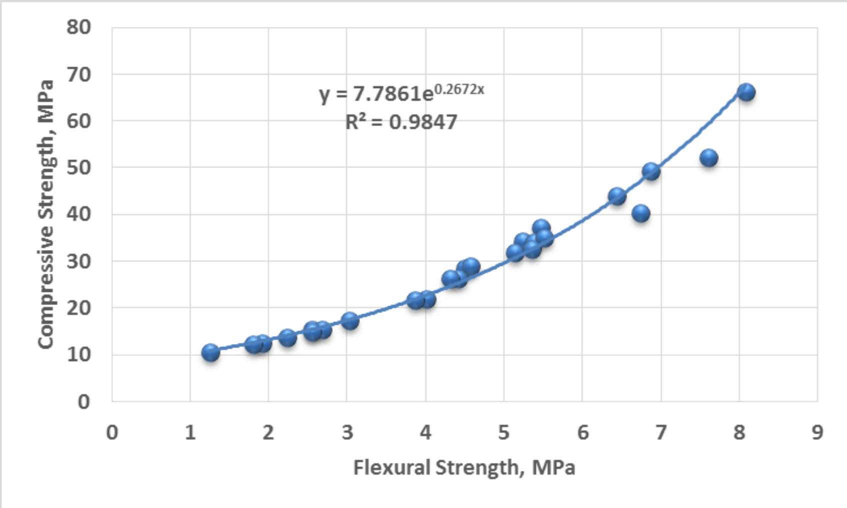

Fig. 9. Compressive strength vs flexural strength of geopolymer concrete bricks

It was observed that the proposed formula often is given higher values in higher compressive strength than the ACI, BS-8110 and IS: 456-2000 international codes. The thickness of the brick (80 mm in this case) may be relatively large to the effective length of the brick (200 mm). Therefore; giving higher values for flexural strength.

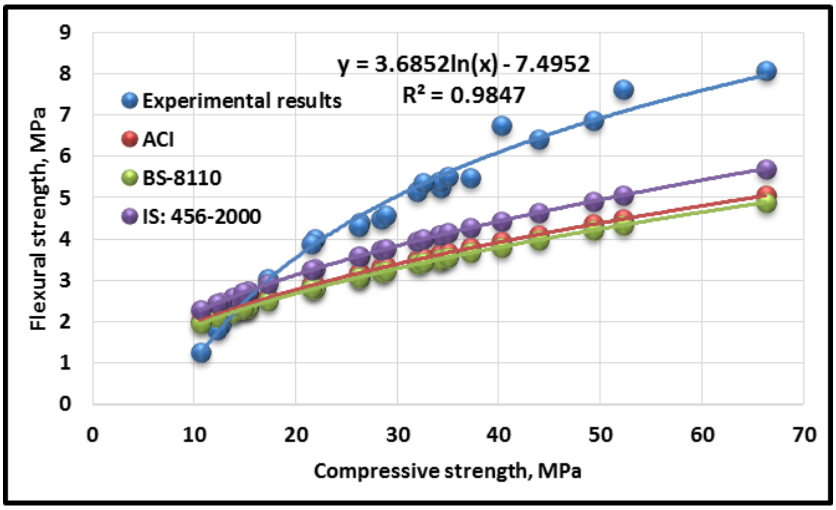

Fig. 10. Validity of the Eq. 9

5.5 Compressive strength

To benefit from modern techniques in non-destructive tests to evaluate the strength of concrete, the following tests were carried out:

5.5.1 *Rebound hammer:* following ASTM C805 [22] standard specification, the rebound hammer test was done. Several factors affect the result of rebound hammer test [23] and [24], such as surface smoothness, rigidity, shape, size of specimens, also the internal and surface moisture of specimens, also size, shape, and type of aggregate. The test was carried out so that the orientation of the rebound hammer was in the longitudinal direction of the geopolymer concrete bricks as shown in Figure 11. The experimental results of the hammer tests used to develop a simple power formula Eq. 10 to predict a relationship between the compressive strength of geopolymer concrete bricks with 96% confidence. The results of the rebound hammer test plotted in Figure 12.

$$fc = 0.3289RN^{1.3041} \tag{10}$$

where: *fc* is compressive strength of concrete bricks, MPa
RN is rebound hammer number

It was observed that it was not possible to obtain values from rebound hammer instrument for geopolymer bricks concrete mixes containing 50% replacement ratio of EPS as a partial replacement of coarse aggregate. The reason may be due to the high porosity ratio and low rigidity of geopolymer concrete bricks with a 50% replacement ratio of EPS as a partial replacement of coarse aggregate.

Fig. 11. Rebound hammer test

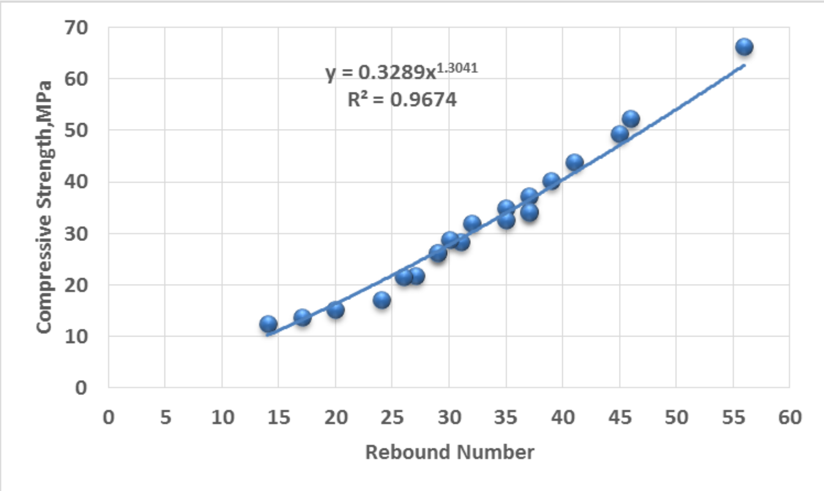

Fig. 12. Compressive strength vs rebound number

5.5.2 Ultrasonic Pulse Velocity (UPV)

Ultrasonic pulse velocity test followed ASTM C597 [25] standard specifications. This test mainly depends on the propagation velocity of ultrasonic during a known length of a given material. The ultrasonic pulse velocity depends directly on the density of the material, the modulus of elasticity, Young's modulus, and Poisson's ratio [26]. The wave was transmitted by a transducer and received by another transducer on the other side of the brick specimens. The ultrasonic velocity was obtained from the L/T ratio, where L is the length of the wave path and T the propagation time of the wave.

The UPV test values of geopolymer concrete bricks were ranged between (5.08 to 3.80) as shown in Table 6 depending on compressive strength, density, and porosity of geopolymer concrete bricks. The experimental results plotted in Figure 13. The results showed increases in UPV values as compressive strength increased. Anyway; the experimental data used to develop a logarithmic formula between compressive strength of geopolymer bricks and UPV as shown in Eq. 11 with 96% confidence.

$$fc = 163.71\ln(UPV) - 205.89 \tag{11}$$

Where: *fc* is compressive strength of concrete bricks, MPa
UPV is Ultrasonic pulse velocity, km/sec

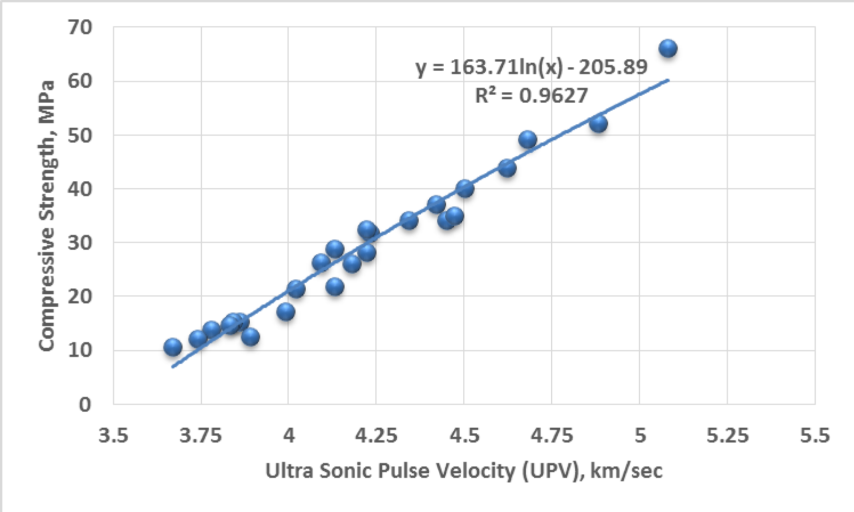

Fig. 13. Compressive strength vs UPV of geopolymer concrete bricks

5.5.3 Combined Use of UPV and Rebound hammer Tests ((SonReb))

For a good correlation between UPV and Rebound hammer tests, ((SonReb)) method can be used. This method combined between results of UPV and RH. It is useful in increasing confidence in predicting concrete strength as well as informing us about the quality of concrete. It will be better for getting a very good quality control of the concrete. The combine method ((SonReb)) looks more suitable for evaluating and predicting concrete strength, fast, reasonable cost and convenient [26]. Once the correlation between concrete strength and nondestructive tests is established, the predicting of concrete strength be more reliable. This method has become widely used and has begun to gain good reliability, provide interesting, sufficient and fairly information to monitor and control the quality of concrete [27].

Many researchers showed that the use of ((SonReb)) method could predict better concrete compressive strength comparing to ultrasonic pulse velocity or rebound hammer test individually. Table 8 shows some predicted empirical formula developed by [28], [29], [30], [31] and [32]:

Table 8
Predicted empirical formula developed by previous researchers

Researcher	Predicted empirical formula
Di Leo et al. [28]	$f_c = 1.2 * 10^{-9} * V^{2.446} * R^{1.058}$
RILEM NDT4 [29]	$f_c = 7.695 * 10^{-11} * V^{2.6} * R^{1.4}$
Gasparik [30]	$f_c = 8.6 * 10^{-8} * V^{1.85} * R^{1.246}$
Tanigawa et al.[31]	$f_c = 0.9R + 0.022V - 94$
C. Sreenivasulu et al.[32]	f_c=7.966*V+ 1.125*R-27.759

The solution to correlate the relationship between experimental data of UPV and Rebound hammer test with experimental compressive strength of geopolymer concrete bricks seems to be by statistical analysis. A statistical analysis of the experimental results was carried out by correlate results of the experimental compressive strength with UPV and RH tests for concrete geopolymer bricks specimens. Using (Origin Lab Pro 2019), a mathematical formula was proposed as below:

$$f_c = 14 * 10^{-5} * V^{1.02} * RN^{1.16} \quad (12)$$

Where: *fc* is compressive strength of geopolymer concrete bricks, MPa

V is ultrasonic pulse velocity, km/sec

RN is rebound hammer number

A significant correlation observed between UPV, RH and experimental compressive strength of geopolymer concrete bricks. The compressive strength of geopolymer concrete bricks can be predicted using the proposed empirical Eq. 12 as shown above with R^2 =98.8%. The proposed empirical equation has been compared with predicted empirical equations developed by [28], [29], [30], [31] and [32] as shown in Figure 14. The predicted results of the compressive strength of geopolymer concrete bricks using empirical Eq. 12 showed excellent compatibility with the empirical equations of previous researchers as shown in Figure 14.

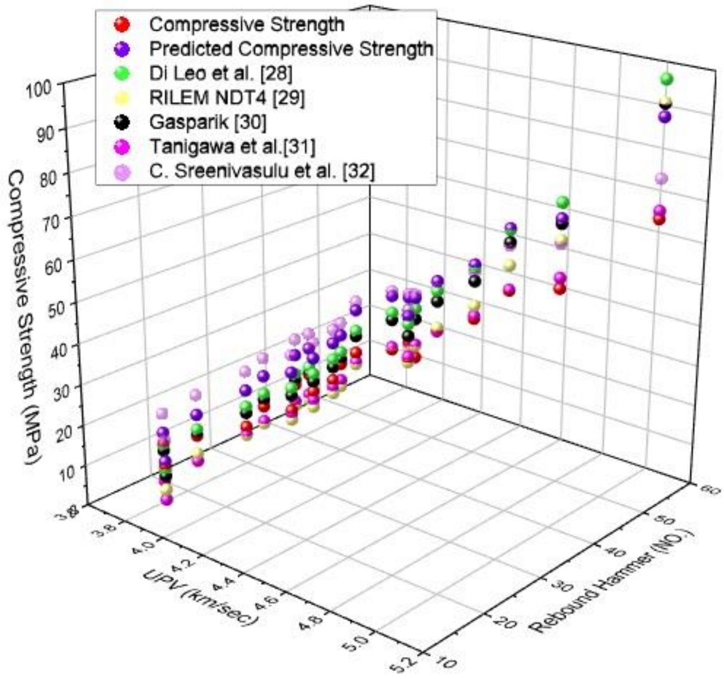

Fig. 14. Comparing the experimental compressive strength with proposed equation and various References equations.

5.5.4 *Effect of EPS and Fly ash*

Effect of replacing EPS as partial replacement ratios of coarse aggregate on compressive strength of geopolymer concrete bricks was observed. However; increasing of EPS replacement ratios from (0, 10, 20, 30, 40 and 50%) of coarse aggregate led to a serious reduction in compressive strength as shown in Figure 15. This behavior was due to the increase in porosity and void ratios led to a decrease in geopolymer concrete density. Generally, there was a slight reduction in compressive strength of geopolymer concrete bricks with increasing of fly ash replacement ratios (as a partial replacement of cement).

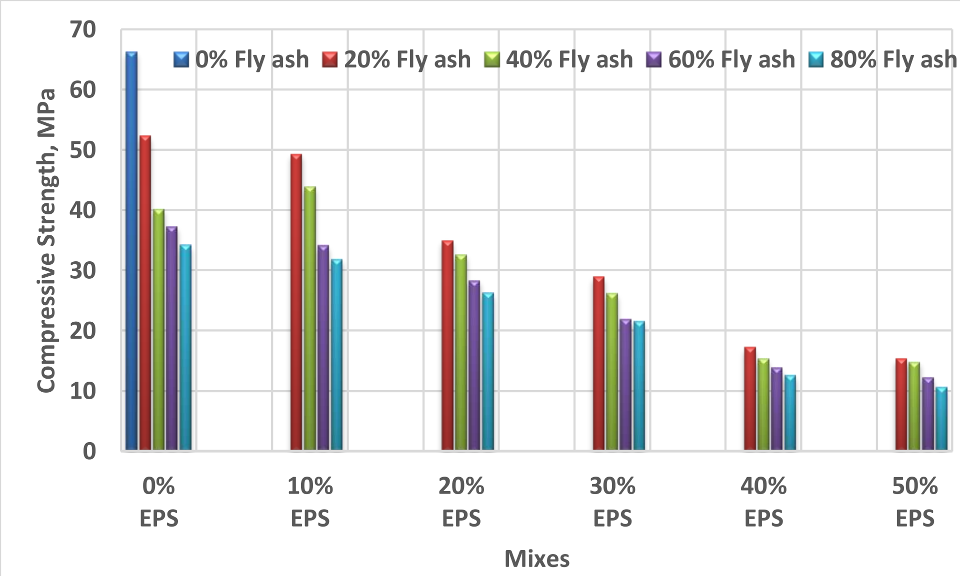

Fig. 15. Effect of EPS and fly ash % on compressive strength of geopolymer concrete bricks

6. Conclusions

The use of expanded polystyrene EPS waste and fly ash through incorporating them into geopolymer concrete bricks have many benefits, including, but not limited to, clearing the environment from these wastes, preserving the natural resources and reducing the use of cement and coarse aggregate in concrete. However, the main conclusions of this study can be summarized as follow:

1. Expanded Polystyrene waste EPS can be incorporate into geopolymer concrete to produce geopolymer concrete bricks without negative chemical reaction between polymeric materials and EPS wastes as it was observed when Brick's structure tested.
2. The water absorption ratio of the geopolymer concrete bricks increased by an increase of the replacement ratios of EPS from 10, 20, 30, 40 and 50% as a partial replacement of coarse aggregate.
3. The experimental results of this study allowed to propose predictive empirical equation (2) to establish a relationship between water absorption ratio and compressive strength of geopolymer concrete bricks with R^2 more than 93%. Also, a predictive empirical equation (5) of the relationship between the porosity ratio and water absorption ratio was proposed. The higher the porosity in geopolymer concrete bricks, the greater the water absorption ratio and the consequence, the compressive strength decreases.
4. The dry density of the geopolymer concrete bricks decreased as the partial replacement ratios of EPS waste increased from 0, 10, 20, 30, 40 and 50%. Thus, it was possible to obtain lightweight-structural strength geopolymer concrete bricks units. That was evidenced in mixes (M16 and M17) at 30% replacement ratio of EPS where dry density decreased to 1867 kg/m3 and 1820 kg/m3, respectively.
5. (SonReb)'s analysis clearly showed the existence of a close correlation coefficient R^2 more than 98% between UPV, RH and experimental results of compressive strength of the geopolymer concrete bricks.

6. The proposed empirical formula of the combined method ((SonReb)) showed excellent compatibility when compared with empirical formulas proposed by previous researchers.

References

[1] Zhang, Haimei, ed. *Building materials in civil engineering*. Elsevier, 2011.

[2] Chandru, G., N. Vijay, V. Vignesh, and Sachin Kumar. "Study on Behaviour of Concrete Blocks with EPS and Partial Replacement of Fly ash and Quarry Dust." *International Journal of Advanced Engineering Research and Science* 4, no. 1 (2017).

[3] Ahmed, S.H. T. and Kumari, K.P. "Experimental Study on MEPS Concrete and Brick using Nano Materials." *International Journal of Innovative Research in ScienceEngineering and Technology* 6 (6), (2017): 11941-11950.

[4] Kalwane, U.B., Autade, P.B. and Patare, D.S. "Effect of Varying Ratio of Silicon Dioxide to Sodium Oxide on Geopolymer Concrete." *International Journal of New Innovations in Engineering and Technology* 5(4), (2016):1-10.

[5] Joseph, D. (2008). *Geopolymer Chemistry and Applications*." 2nd Ed., Institute Geopolymere, St. Quentin, France.

[6] Bhikshma, V., Reddy, M.K. and Rao, T.S. "An Experimental Investigation on Properties of Geopolymer Concrete (No Cement Concrete)." *Asian Journal of Civil engineering (Building and housing)* 13 (6), (2012): 841-853.

[7] ASTM C150 / C150M-19a, Standard Specification for Portland Cement, ASTM International, West Conshohocken, PA, 2019.

[8] ASTM C618-19, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, ASTM International, West Conshohocken, PA, 2019.

[9] B.S 882 (1992). Specifications for Aggregate from Natural Sources for Concrete. British standards.

[10] ASTM C494 / C494M-17, Standard Specification for Chemical Admixtures for Concrete, ASTM International, West Conshohocken, PA, 2017.

[11] Pavithra, P., Reddy, M.S., Dinakar, P., Rao, B.H., Satpathy, B.K. and Mohanty, A.N. "A mix design procedure for geopolymer concrete with fly ash." *Journal of Cleaner Production*, (2016): 133, 117-125 http://dx.doi.org/10.1016/j.jclepro.2016.05.041

[12] Patankar, , Ghugal, and Jamkar, (2015). "Mix Design of Fly Ash Based Geopolymer Concrete." *Advances in Structural Engineering Conference, Springer, New Delhi*, pp 1619-1634. 2015. https://doi.org/10.1007/978-81-322-2187-6_123

[13] Hardjito, D., Wallah, S.E., Sumajouw, D.M.J, and Rangan, B.V., (2004). "On Development of FA-Based Geopolemer Concrete." *ACI Materials Journal*, vol. 101, No.6, (2004): pp. 467-472.

[14] Mustata Al Bakri, AM., Kamarudin H., Bnhussain, M., Rafiza, A.R., and Zarlna, Y. "Effect of Na2SiOs/NaOH Ratios and NaOH Molarities on Compressive Strength of Fly-Ash-Based Geopolymer." *ACI Materials Journal*, vol. 109, No.5, (2012): pp.503-508.

[15] ASTM C67 / C67M-19, Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile, ASTM International, West Conshohocken, PA, 2019.

[16] Hernández-Zaragoza, J.B., Lara, T.L., Rangel, J.H., Cajún, C.L., González, E.R., Rodríguez, F.J.G., Adue, J. "Cellular Concrete Bricks with Recycled Expanded Polystyrene Aggregate." *Advances in Materials Science and Engineering*, Volume 2013, (2013): Article ID 160162, 5 pages. http://dx.doi.org/10.1155/2013/160162

[17] Thokchom, S., Ghosh, P. and Ghosh, S. "Effect of Water Absorption, Porosity and Sorptivity on Durability of Geopolymer Mortars." *ARPN Journal of Engineering and Applied Sciences*, Vol. 4, No. 7, (2009): pp. 28-32.

[18] ASTM C140 / C140M-18, Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units, ASTM International, West Conshohocken, PA, 2018.

[19] Alsayed, S.H. and Amjad, M.A. "Strength, Water Absorption and Porosity of Concrete Incorporating Natural and Crushed Aggregate." *Journal of King Saud University*, Vol. 8, Eng. Sci. (1), (1994): pp. 109-120.

[20] Farhana, Z.F., Kamarudin, H., Rahmat, A. and Mustafa Al Bakri, A.M."The Relationship between Water Absorption and Porosity for Geopolymer Paste." *Materials Science Forum* Vol. 803, (2015): pp 166-172. doi:10.4028/www.scientific.net/MSF.803.166

[21] Yusuf, I.T., Jimoh, Y.A. and Salami, W.A."An appropriate relationship between flexural strength and compressive strength of palm kernel shell concrete." *Alexandria Engineering Journal*, Vol. 55, (2016): pp.1553–1562. http://dx.doi.org/10.1016/j.aej.2016.04.008

[22] ASTM C805 / C805M-18, Standard Test Method for Rebound Number of Hardened Concrete, ASTM International, West Conshohocken, PA, 2018.

[23] Bungey, J.H. and Millard, S.G. (1996). "Testing of Concrete in Structures," 3rd Edition, Blackie Academic & Professional, London.

[24] Malhotra, V.M. and Carino, N.J. (1991). "CRC Handbook on Nondestructive Testing of Concrete," CRC Press, Boca Raton.

[25] ASTM C597-16, Standard Test Method for Pulse Velocity Through Concrete, ASTM International, West Conshohocken, PA, 2016.
[26] Giovanna, C., Barbara, D., Luisa, P., Nicoletta, T., and Monica, V.”Prediction of Concrete Compressive Strength by Means of Combined non-destructive Testing.” *Advanced Materials Research*, Vol. 894, (2014): pp 77-81.
[27] Hannachi, S. and Guetteche, M.N.”Application of the Combined Method for Evaluating the Compressive Strength of Concrete on Site.” Open Journal of Civil Engineering, Vol. 2, (2012): pp. 16-21.
[28] Di Leo, A., Pascale, G. (1994): IL GIORNALE DELLE PROVE NON DISTRUTTIVE, vol.4.
[29] RILEM NDT 4 (1993): Recommendation for in situ concrete strength determination by non- destructive combined methods, Compendium of RILEM Technical Recommendations, E&FN Spon, London.
[30] Gasparik, J. (1992): QUADERNO DIDATTICO, AIPND, Brescia.
[31] Tanigawa, Y., Baba, K. and Mori, H. (1984): Proc. of In Situ/Nondestructive Testing of Concrete, Detroit, American Concrete Institute, SP-82, pp. 57-76.
[32] Sreenivasulu, C., Guru Jawahar, J. and Sashidhar, C.”Predicting compressive strength of geopolymer concrete using NDT techniques.” *Asian Journal of Civil Engineering*, (2018): https://doi.org/10.1007/s42107-018-0036-1(01