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Experimental Investigation of the Production of Sustainable Lightweight Concrete

Mouhammed J. Lafta [a]

[a] Engineering and Technology Journal, University of Technology, Baghdad, Iraq.
10959@uotechnology.edu.iq

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K E Y W O R D S

Coarse aggregate, lightweight concrete, non-structural concrete, pumice.

A B S T R A C T

An experimental study on four types of coarse aggregate was conducted to produce lightweight concrete. These four types are namely; white limestone, red limestone, clay brick fragments, and pumice. Ordinary Portland cement was used for all examined mixes. Water to cement ratio (w/c) was modified according to the effect of coarse aggregate type on the workability of the resulted concrete for each mix. The reference concrete mix, which is normal concrete, water to cement ratio used was (0.5). The investigated characteristics for all concrete mixes were workability, compressive strength, dry density, absorption, and thermal conductivity. Results indicated that the aggregate type significantly affects most of the properties of lightweight concrete mixes such as workability, density, and thermal insulation for all tested types of concrete. All investigated specimens indicated improvement in terms of density, workability, and thermal conductivity when compared to the reference concrete mix. Yet, it was derived from the testing results that using pumice in lightweight concrete production is the optimum option among the other examined types. When compared to normal concrete, this type of lightweight concrete showed a 41% decrease in dry density, nearly 72.54% decrease in thermal conductivity, and about 12% increase in workability. However, it is vital to notice that due to the low compressive strength and the relatively high absorption capability for all the examined types of lightweight concrete, it is suggested to use these types of concrete for non-structural walls that are not subjected to or exposed to high humidity.

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1. Introduction

In the field of construction, concrete is considered as the most common building material that is used for a variety of projects' types [1]. In terms of concrete mortar or filling materials, the guidelines for its sustainability are basically based on three main characteristics. These three characteristics are the reduction of cement consumption, materials recycling, and designs [2]. The self-weight of construction projects is considered as the vast part of the total dead load in their structures. Hence, tremendous benefits can be obtained by decreasing the density of concrete as it can significantly reduce the dead load of the construction. Therefore, the use of lightweight concrete can assist in reducing the dead loading for structures, which can lead to many other benefits such as decreasing the construction cost. Additionally, other desired characteristics can be obtained by the use of lightweight concrete. For instance, thermal conductivity can be significantly improved using this type of concrete.

The most common method to produce such types of concrete is the inclusion of pozzolanic materials such as silica steam and fly ash. Moreover, the use of crushed aggregate from glass wastes, clay brick, ceramic, and crushed stones can assist to produce lightweight concrete [3]. There are many studies on the production and properties enhancement of lightweight concrete in the literature. An approach to use thermosetting plastic in the production of non-structural lightweight concrete was implemented by Phaiboon Panyakapo and Mallika Panyakapo. [4]. The fact that this type of plastic cannot be melted in the recycling process made the author expect this waste to be more valuable by using as an admixture for the production in the mix proportion of lightweight concrete. According to the finding of this study, the produced concrete meets most of the requirements for non-load-bearing lightweight concrete, which comply with ASTM C129 Type II. Results of compressive strength and dry density obtained from their experimental investigation reported being 4.14 MPa and 1395 kg/m3, respectively. Ergul Yasar et. al designed a structural lightweight concrete made with basaltic pumice as coarse aggregate and fly ash as mineral admixtures [5]. Compressive and tensile strength test results obtained from this research work showed that structural lightweight concrete can be produced by the use of basaltic pumice as aggregate. In another attempt to produce a different type of lightweight concrete, Richard and Ramli conducted a study on the base mix parameters to produce a sustainable foamed concrete by replacing cement with other cementitious material, namely fly ash [6]. Results, driven from this research, divulge that with a range of 10% cement replacement a high strength sustainable foamed concrete can be produced. A different approach to produce lightweight concrete was carried out by Hossain through investigating the suitability of using volcanic pumice as an alternative for both and coarse aggregate [7]. The test involved replacing cement by a range of (0%-25%) by weight and replacing coarse aggregate in concrete by a range of (0%-100%) by volume. Tests on workability, drying shrinkage, permeability, strength, and surface absorption were performed in this study to assess the resulted volcanic pumice concrete using different volcanic pumice aggregate. The study concludes that, when compared to control concrete, this type of lightweight concrete had many improved characteristics such as satisfactory density and adequate strength. Yet, it had a lower modulus of elasticity and high permeability and initial surface absorption.

The properties of lightweight foamed concrete, produced by using the wastes of clay brick to serve as a substitute, were investigated by researchers as well. Ibrahim et. al [8] carried out an investigation to evaluate the possibility of decreasing the depletion of normal coarse aggregate from granite by utilizing different percentages of clay brick waste in the concrete mix. The percentage of clay brick wastes used in this investigation were 25%, 50%, 75%, and 100%. Results revealed that the lightweight concrete mix with 25% altering of clay brick waste has the highest value of compressive strength among all other examined mixes. Harun and Ahmet studied the effect of high temperature on compressive and splitting tensile strength of lightweight concrete containing fly ash [9]. This study provided a resolution of the importance level of the percentage of fly ash and heating on both compressive and tensile strength.

There are many methods to produce lightweight concrete and to evaluate its versatile properties. Although numerous studies have recognized the production of lightweight concrete, most researches have yet systematically investigated the production of lightweight concrete using one type of lightweight aggregate. No study investigated four types of lightweight concrete altogether and compared their test results in order to better understand the topic of lightweight aggregate production.

This paper studies the production of lightweight concrete through an experimental study investigation of four types of lightweight coarse aggregate. These four types are white limestone, red limestone, pumice, and clay brick fragments. Different physical and mechanical characteristics of lightweight concrete, such as workability, compressive strength, dry density, absorption, and thermal conductivity were evaluated.

2. PROPERTIES OF THE USED MATERIALS

I. Cement

Ordinary Portland cement was used for concrete mixes of this research experimental work. Tests such as consistency, setting time (initial and final), and compressive strength were performed to ensure that the cement complies with IQS (No. 5, 1984) [10]. Physical properties and chemical properties testing results are shown in Tables 1 and 2 respectively.

TABLE I: Physical properties of Ordinary Portland cement

Tested property	Results	Accepted Limits According to Iraqi Specification No.5, 1984 [10]
Fineness (m^2/kg)	295	230
Consistency (%)	0.35	≤0.8
Setting Time:		
-Initial (min.)	130	≥45
-Final (hr.)	3.3	≤10
Compressive		
Strength (MPa):	22.7	≥15
-At age (3) days.	31.5	≥23
-At age (7) days.		

TABLE II: Chemical properties of Ordinary Portland cement

Oxide	Results	Limits According to Iraqi Specification No.5, 1984 [10]
SiO_2	21.03	-
Al_2O_3	5.38	-
Fe_2O_3	3.4	-
CaO	60.4	-
SO_3	2.58	≤2.8%
MgO	2.55	≤5%
L.O.I	2.79	≤4%
I.R	1.21	≤1.5%
L.S.R	0.87	0.66-1.02
C_3S	47. 16	-
C_2S	25.29	-
C_3A	8.51	-
CA_4F	10.44	-

II. Coarse Aggregate

Different types of crushed stones were used in this research work. River gravel was used as coarse aggregate for the reference concrete mix. Five types of course aggregate were used. These types are listed below:

1. River gravel.
2. Clay bricks fragments.
3. Red limestone (crushed).
4. White limestone (crushed).
5. Pumice or black stone.

River gravel

River gravel was used in the reference mix. The sample of this type of gravel was prepared by gathering sizes of this type of gravel in a range of grading that complies with the American Standards for Testing Materials (ASTM) C330 [11]. This is shown in detail in Table 3. Other properties of this type of gravel were investigated as well and the results are shown in Table 4.

TABLE III: Sieve analysis of gravel

Sieve openings diameter (mm)	Passing (%)	ASTM C330 limitations [11]
12.5	100	100
9.5	83	80-100
4.75	12	5-40
2.36	5	0-20
1.18	3	0-10

TABLE IV: Physical properties of the gravel

Test	Results
Specific weight	2.68
Absorption (%)	0.6
Sulfate content (%)	0.06

Clay Brick Fragments

Clay brick is the most common construction unit used in construction works in Iraq. Debris of clay brick - wastes produced from transferring, loading, and unloading bricks were used as a replacement of gravel in the concrete mix. However, before using this type of crushed bricks in a concrete mix for this research work, it had to go through the following procedure:

1. The clay bricks fragments were crushed into small pieces manually using a hammer to achieve the desired size (maximum largest dimension is 9.5 mm). Figure 1 shows samples of crushed clay brick fragments.
2. The crushed clay fragments were sieved using standard mechanical sieves for ten minutes. After that, dividing the resulted crushed bricks into different parts according to sieves. Then, the sample of crushed stone is prepared by collecting the required sizes to be within the range of natural coarse aggregate grading which complies with ASTM C330) [11]. More details are shown in Table 5.
3. The collected sample is then washed using water to remove the dust of its surface. After that, the sample is submerged in water for 24 hours.
4. Finally, the surface of the sample is wiped out with a piece of clothes or a brush for an appropriate period in order to get a dry surface saturated voids sample.

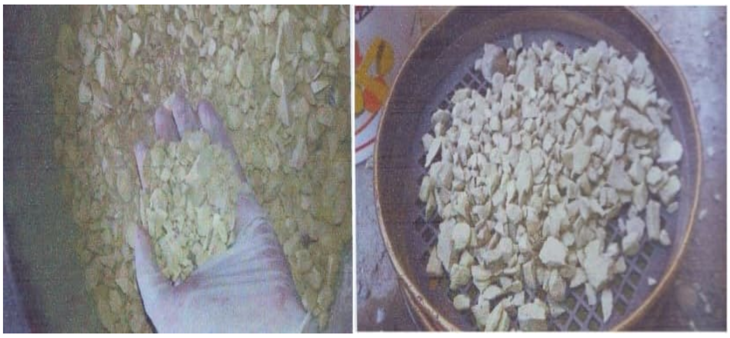

Figure 1: Crushed clay brick fragments

TABLE V: Sieve analysis of clay brick fragments aggregate

Sieve opening diameter (mm)	Passing (%)	ASTM C330 limitations [11]
12.5	100	100
9.5	91	80-100
4.75	30.5	5-40
2.36	10	0-20
1.18	4	0-10

Red limestone

The wastes of red limestone, which simply result from loading, unloading, and transferring this stone were used in the work of this research. A similar procedure, that was followed when preparing clay brick fragments, was also utilized to prepare the red limestone to be used as a replacement of gravel for a concrete mixture. This type of aggregate was prepared in a way makes it comply with ASTM C330 [11]. Table 6 shows the results of the sieve analysis of this type of aggregate.

TABLE VI:Sieve analysis of red limestone aggregate

Sieve opening diameter (mm)	Passing (%)	ASTM C330 limitations [11]
12.5	100	100
9.5	86	80-100
4.75	35	5-40
2.36	9	0-20
1.18	3	0-10

White limestone

The wastes of white limestone were used as the second option of gravel replacement in concrete. White limestone forms from sedimentary rocks. A sample is shown in Figure 2. It consists of silica, pure limestone, and some impurities. Mainly its color is white, but it can be found in different colors such as yellow and grey. This is due to some impurities that are within it such as sand, iron oxide, and clay. In general, white limestone forms in very fine grains or coarse grains. Sometimes, it forms as veins through the soil.

The wastes of this type of stone were used for this research work. The same procedure followed when preparing clay brick fragments was also followed to prepare this type of aggregate. Table 7 shows the sieve analysis for crushed white limestone used in this research work.

Figure 2: White limestone sample

TABLE VII: Sieve analysis of white limestone aggregate

Sieve opening diameter (mm)	Passing (%)	ASTM C330 limitations [11]
12.5	100	100
9.5	82	80-100
4.75	10	5-40
2.36	9	0-20
1.18	2	0-10

Pumice

Pumice is a lightweight glassy volcanic rock. It is formed from volcanic ash. Therefore, it is usually porous and filled with holes resulted from the retention of some gas bubbles during the hardening procedure of this type of stone. This type of stone is more likely to be defined as a volcanic glass that is formed as foam filled with hot gas bubbles. It cools rapidly causing the gas bubbles to be trapped within it as pores. Table 8 shows the sieve analysis for crushed white limestone used in this research work. Figure 3 shows a sample of pumice.

Figure 3: Pumice sample

TABLE VIII: Sieve analysis of pumice

Sieve opening diameter (mm)	Passing (%)	ASTM C330 limitations [11]
12.5	100	100
9.5	80.5	80-100
4.75	25	5-40
2.36	15	0-20
1.18	5	0-10

III. Specific weight and absorption of coarse aggregate

Test of specific weight and absorption was performed for all four types of aggregate used in this research work according to ASTM C127 [12]. The results of these tests are shown in Table 9.

TABLE IX:Specific weight and absorption tests' results of coarse aggregate

Type of coarse aggregate	Absorption (%)	Specific weight
River gravel	0.6	2.68
Crushed clay brick	21	2.13
Crushed red limestone	13	2.33
Crushed white limestone	8.6	2.44
Crushed pumice	35	1.64

IV. Fine aggregate (sand)

Local sand, known commercially as Al-Akhedher sand, was used in all concrete mixtures. The maximum grains size for this type of sand is (4.75) mm which complies with ASTM C330 [11]. The results of the sieve analysis are shown in Table 10. The sand specimen was also washed and then dried in the laboratory for an appropriate period in order to achieve a dry surface dry and to ensure that voids are fully saturated. Other physical properties of sand are shown in Table 11.

TABLE X: Sieve analysis of fine aggregate (sand)

Sieve opening diameter (mm)	Accumulated remained (%)	Passing (%)	ASTM C330 limitations [11]
9.5	0	100	100
4.75	5	95	85-100
1.18	34	66	40-80
300µm	85.4	14.6	10-35
150µm	96.45	3.55	5-25

TABLE XI:Physical properties of sand

Test	Results
Specific weight	2.63
Absorption (%)	2.1
Sulfate content (%)	0.27
Fineness modulus	1.76

3. EXPERIMENTAL WORK

A concrete mix of ratio (1:2:4) was used to produce the reference mix and to produce the required concrete mixes using different types of crushed stones, namely pumice, white limestone, red limestone, and clay bricks fragments. This ratio was basically selected for this research work due to its common utilization in many constructions' works, especially in Iraq. A (150) mm cubic molds were used to prepare the samples for this study.

In order to perform the sampling, 15 samples of each type of stone, used in this research, were prepared. Another 15 samples of the ordinary concrete mix were prepared as well. These samples were used as a reference. The results from other lightweight concrete samples were compared with the results from samples of reference concrete mix. A study of the effect of the suggested lightweight aggregate types on the density of the concrete mix, concrete absorption, and strength was performed at three ages of concrete samples The first mix consists of ordinary concrete mix components (i.e.: cement, sand, gravel, and water). No crushed stones were used in the first concrete mix. On the other hand, the second, third, fourth, and fifth mixes consist of different types of crushed stones as a replacement of gravel. The grading of crushed stones sizes complies with ASTM C330 [11]. These stones have a specific weight less than gravel, which can assist in producing sustainable lightweight concrete, which is the aim of this investigation.

I. Preparation of Concrete Mixes and Testing Specimens

Since most of the aggregate types used in this research work were high in porous, the high absorption property was put into consideration. These types of aggregate were submerged in water for 24 hours and then dried with a dry cloth. In this manner, the coarse aggregate would be at saturated surface-dry condition before using it in concrete mixes. This will ensure that the coarse aggregate does not absorb the water of the mixture. After preparing all materials according to their weight portions, the ordinary mean of mixing lightweight aggregate was followed. This procedure of mixing is considered one of the easiest ways of mixing, from a practicality point of view, and the best way to assure getting the desired properties for concrete mix especially the density of concrete.

First, the aggregate was mixed with half of the mixing water amount. Then, cement was added along with the rest of the mixing water to mix for two additional minutes. After that, the mixing was performed using ordinary mechanical rotary mixer complying with ASTM C192 [13]. Mixing was performed until a plastic coherent concrete mix was achieved without having extra smoothness. Five types of concrete mixes were prepared; one for each type of coarse aggregate. Finally, concrete was poured in iron molds (150*150*150) mm in dimension. Table 12 shows the description and number of samples of concrete used in this research work.

TABLE XII: Mixes and sampling details

Mix	*W/C ratio*	**No. samples/cubes used for testing**				
		Compressive strength at age (7) days	*Compressive strength at age (14) days*	*Compressive strength at age (28) days*	*Dry density (kg/m^3) at age 28 days*	*Absorption (%) at 28 days age*
A	0.5	3	3	3	3	3
B	0.57	3	3	3	3	3
C	0.6	3	3	3	3	3
D	0.58	3	3	3	3	3
P	0.66	3	3	3	3	3

.

Where:
Mix A: Represents the reference concrete mix (normal concrete mix).
Mix B: Represents a concrete mix with white limestone aggregate.
Mix C: Represents a concrete mix with clay brick fragments aggregate.
Mix D: Represents concrete mix with red limestone aggregate.
Mix P: Represents a concrete mix with pumice aggregate.

II. Fresh Concrete Tests

Workability was measured for all produced concrete mixes by implementing a slump test according to ASTM C143 [14].

Hardened Concrete Tests

Oven Dry Density Testing (Dried-In-Oven Sample)

This test was performed according to ASTM C567 [15]. Three cubes of size (150*150*150) mm were used. The average of their densities at the age of 28 days was taken for each mix. The following steps illustrate the procedure:

1. Concrete cubes were submerged in water for (28) days. Then, cubes were weighed when they are submerged in water.
2. The surfaces of the concrete cubes were dried using a rug. The concrete cubes were exposed to laboratory conditions for an appropriate period. This way assures getting dry surface- saturated concrete cube.
3. The concrete cubes put in the laboratory oven for 24 hours and heated to (105 ±5) ^{o}C [16]. After that, the concrete cubes were weighed. Equation 1 was applied in order to calculate the dry density of the concrete cube in (kg/m^3):

$$om\left(Density, \frac{kg}{m^3}\right) = \frac{(D\times 997)}{F-G} \quad (1)$$

Where:
om : Dry density of a well-dried concrete cube in laboratory oven (kg/m^3).
D: dry weight in laboratory oven (kg).
F: the weight of a dry surface-saturated concrete cube (kg).
G: the weight of a submerged concrete cube in water (kg).

III. Compressive Strength Test

The compressive strength test was performed, for all samples, for each mix at ages (7, 14, 28) days; Three cubes for each age. The experimental part of this study was performed in the laboratories of Material and Structure, Civil Engineering Department, University of Technology. BS1881-116 was followed when testing for compressive strength of concrete for this research work.

IV. Thermal Conductivity

Thermal conductivity was evaluated for all types of mixes' samples used in this research work. The thermal conductivity factor, which represents the heat insulation, is defined as the number of thermal units that pass through unit area of matter which has a thickness of one length unit, in a one-time unit [16]. In the metric units system, the unit of thermal conductivity is (W/m*k). It measured for concrete submerged in curing water at (23±5) ^{o}C for (28) days. Thermal conductivity was measured according to ACI 523 [16] using Eq. 2 below:

$$K = 0.072e^{0.00125\rho} \quad (2)$$

Where:
K: thermal conductivity (W/m*k) for an oven-dried sample.
ρ: dry density for the sample (kg/m^3).

V. Absorption test

This test was performed for all concrete mixes of this work. Three cubes for each mix were tested. The specification followed for this test was the British Specification (BS 1881: part 122: 1983) [17]. Samples were submerged in water for (24) hours. Then, they were weighed after drying them out using a laboratory oven at a temperature of (100 ± 5 ^{o}C). The water absorption percentage was calculated using the following equation:

$$A = \frac{W-D}{D} \times 100\% \quad (3)$$

Where:
A: water absorption percentage.
D: the dry weight of the sample (kg).
W: the weight of the saturated surface dry sample (kg).

4. Results and Discussion

I. Slump Test

This test was executed according to ASTM C143 [14]. Results shown in Table 13 indicate that the slump for Mix A was (150) mm. It was noticed that, comparing the slump test for normal concrete mix, the slump concrete mix with pumice (i.e.: Mix P) 12.5% higher. Therefore, the water to cement ratio in Mix P was fixed at (0.5) as used in Mix A. Conversely, for other mixes, results showed a significant decrease in slump and workability by (14.2%) in comparison to slump of Mix A. Slump for the concrete mix with white limestone aggregate, Mix B, was (28.5%) less than the slump measured for Mix A. Whereas slump measured for the concrete mix with red limestone aggregate, Mix D, was (21.4%) less than what measured for Mix A. Therefore, in order to increase workability for these concrete mixes, the water to cement ratio was increased in each mix to a specific amount. Many W/C trail ratios were used in different mixes in order to achieve the desired workability that complies with ASTM C143. For concrete mix with brick fragments aggregate, Mix C, water to cement ratio used was (0.56). This assisted to increase the slump amount for this mix from (12) cm to (15) cm. While for the concrete mix with white limestone aggregate, Mix B, the water to cement ratio was increased to be (0.67) which assisted to increase slump to be (135) mm. As for the concrete mix with red limestone aggregate, Mix D, the water to cement ratio was increased to be (0.65). This helped to increase the slump amount for this mix to be (145) mm. Figure 4 shows the percentage variation of the slump amount for all mixes in comparison to mix (A).

TABLE XIII: Slump testing results for concrete mixes

Mix	Description	Preliminary W/C	Slump (mm)	Adjusted W/C	Slump (mm)
A	Reference mix	0.5	150	0.5	150
B	Concrete mix with white limestone	0.5	100	0.67	135

	aggregate				
C	Concrete mix with clay brick fragments aggregate	0.5	120	0.56	150
D	Concrete mix with red limestone aggregate	0.5	110	0.65	145
P	Concrete mix with pumice aggregate	0.5	160	0.5	160

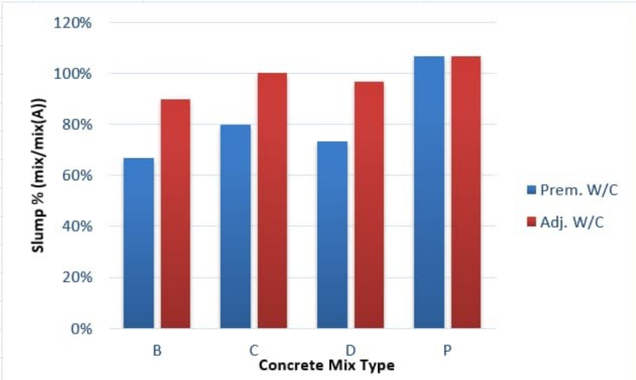

Figure 4: The percentage variation of slump amount for all mixes in comparison to Mix (A)

It is can be observed from these results that, when compared to all other mixes, concrete Mix P has the highest slump percentage due to its relatively well-graded form. Hence, higher workability is obtained. While for Mix B, it is was expected to result in the lowest slump percentage due to the geometry of the stones.

II. Compressive Strength Testing

The test was carried out for all samples at ages (7, 14, and 28) days in an average of three concrete cubes for each age as shown in Table 14. The variation of compressive strength of mixes at different ages is shown in Figure 5. It was noticed from results of compressive strength for all concrete mixes B, C, D, and P, that the lowest value of compressive strength was for Mix P. The main reason of such behavior is the low strength of aggregate used for these concrete mixes in comparison to the natural aggregate (gravel) and due to the increase of w/c ratio. However, as seen from previous studies, this amount of strength of concrete mixes can be accepted for constructing walls or any nonstructural concrete applications.

TABLE XIV: Compressive strength testing results

Mix	Description	W/C	Average compressive strength (MPa) at age: (7) days	(14) days	(28) days
A	Reference mix	0.5	27	30	38
B	Concrete mix with white limestone aggregate	0.67	7.1	8	9.9
C	Concrete mix with clay brick fragments aggregate	0.56	6.4	7.3	8
D	Concrete mix with red limestone aggregate	0.65	8.2	10.1	11.2
P	Concrete mix with pumice aggregate	0.5	5.8	6.2	7.5

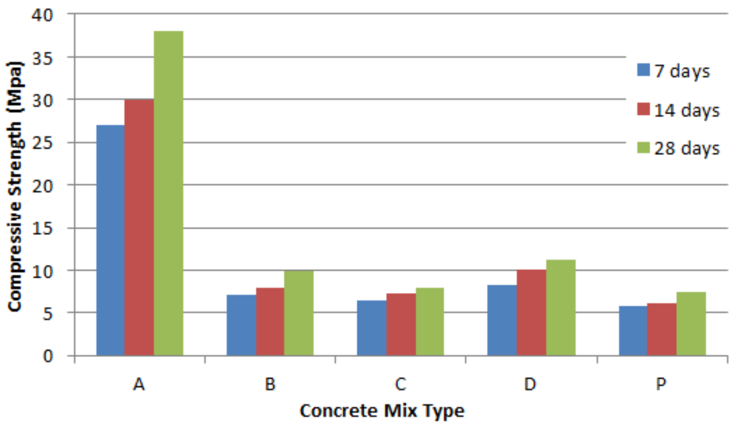

Figure 5: Variation of compressive strength of mixes with time

A comparison of the compressive strength of Mix B and Mix P is shown in Figure 6. It is observed that the compressive strength for Mix B was higher and even increased with time more than for Mix P. This is clearly due to the characteristics of the aggregate used in each mix. By comparing the results from Table 11, it can be observed that the limestone, which is used in Mix B, has a higher density than pumice, hence, higher strength for Mix B. Additionally, the geometric of limestone aggregate makes it interlock more than pumice aggregate. Hereafter, high compressive strength is expected to be gained for Mix B.

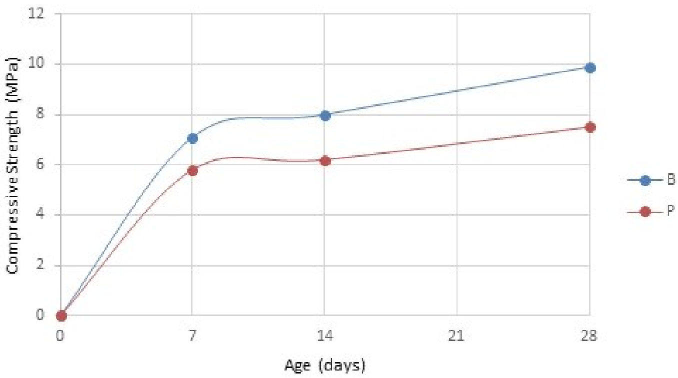

Figure 6: A comparison of compressive strength of Mix B and Mix P at ages 7, 14, and 28 days

III. Oven Dry Density Testing

The ASTM C567 [15] was followed when performing this test. Results of this test shown in Table 15 indicate that among all concrete mixes produced in this research work, the concrete mix with pumice aggregate has the lowest density. Its oven-dry density equals (1420) kg/m^3, which is (41.94%) less than the density of the normal concrete mix, Mix A. The reason for such low density is due to the pumice aggregate with low density according to its highly porous and voids. This makes concrete mix produced using this type of stone low in density. Concrete produced using brick fragments aggregate density was (1787) kg/m^3. This density is also less than what resulted from the density of Mix A in about (26.92%). However, this result still complies with the followed standard (i.e.: ASTM C330-04) (14) for lightweight concrete. As for concrete produced using white limestone aggregate, density was equal to (1930) kg/m^3, which is (21.09%) less than what resulted from Mix A. While for concrete produced using red limestone aggregate, the dry density was (1852) kg/m^3. This density is about (24.28%) less than what resulted from Mix A.

TABLE XV: Oven dry density testing results

Concrete mix type	Description	Oven dry density (kg/m3)
A	Reference mix	2446
B	Concrete mix with white limestone aggregate	1930
C	Concrete mix with clay brick fragments aggregate	1787
D	Concrete mix with red limestone aggregate	1852
P	Concrete mix with pumice aggregate	1420

IV. Absorption Test

It is obvious from the results shown in Table 16 that each type of aggregate has an essential effect on the absorption capability of concrete. Results showed that concrete produced from using pumice aggregate, Mix P, has high absorption in comparison to reference concrete or any other types of concrete produced in this research work. Absorption percentage of Mix P was about (14.4%), which is about (63.1%) higher than what resulted from reference concrete, Mix A. Results has also indicated that all other types of mixes have high absorption percentages in comparison to Mix A. Concrete produced using clay brick aggregate resulted in (13.2%) absorption percentage, which is (59.8%) higher than results from Mix A. For concrete produced using white limestone aggregate, the absorption was (10.1%), which is (47.5%) higher than results from Mix A. As for concrete produced using red limestone aggregate, the result of absorption percentage was (9.8%), which is (45.9%) higher than results from Mix A. Figure 7 shows the percentage of absorption for all mixes in comparison to Mix A.

TABLE XVI: Absorption testing results

Mix	Description	Absorption (%)
A	Reference mix	5.3
B	Concrete mix with white limestone aggregate	10.1
C	Concrete mix with clay brick fragments aggregate	13.2
D	Concrete mix with red limestone aggregate	9.8
P	Concrete mix with pumice aggregate	14.4

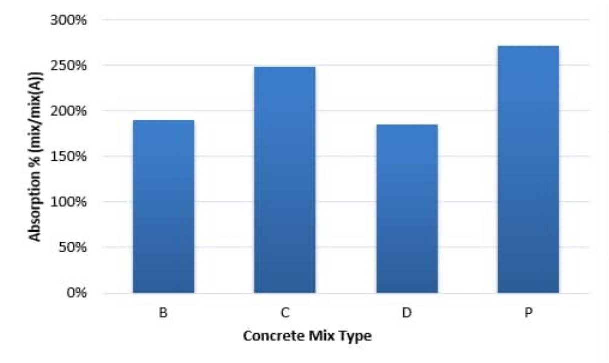

Figure 7: The percentage change of slump for all mixes in comparison to Mix A

V. Thermal Conductivity

Results of thermal conductivity which are shown in Table 17 indicate that the reference concrete mix has (1.53 W/m*k) thermal conductivity. When replacing normal aggregate with clay brick fragments aggregate, thermal conductivity reduces by (56.2%) in comparison to the reference concrete mix, Mix A. Whereas for the concrete mix with white limestone aggregate, thermal conductivity lessened by (47.71%) in comparison to Mix A. while for the concrete mix with red limestone aggregate and concrete mix with pumice aggregate, thermal conductivity reduced by (52.94%) and (72.54%) respectively in comparison to Mix A. It was noticed that concrete mix with pumice aggregate showed the highest percentage of thermal conductivity reduction among all mixes. This is due to the low density of pumice and the high percentage of voids within this type of stone lattice. Figure 8 shows the relationship between thermal conductivity and density of aggregate used of all types of concrete mixes used for this research work.

TABLE XVII: Thermal conducting testing results

Mix	Description	Thermal conductivity average of three samples (W/m*k)
A	Reference mix	1.53
B	Concrete mix with white limestone aggregate	0.8
C	Concrete mix with clay brick fragments aggregate	0.67
D	Concrete mix with red limestone aggregate	0.72
P	Concrete mix with pumice aggregate	0.42

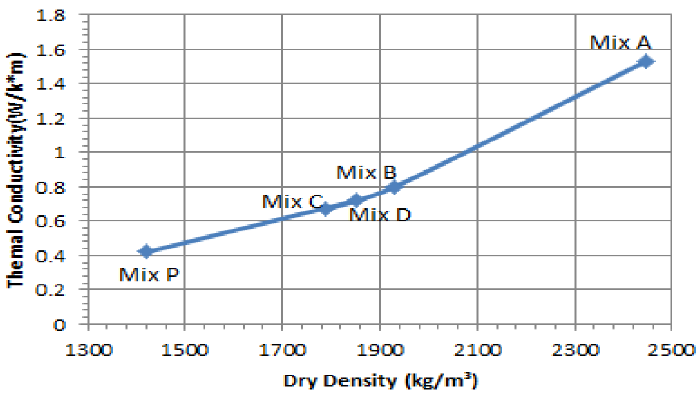

Figure 8: The relationship between thermal conductivity and dry density of concrete

5. CONCLUSIONS

Depending on the results of this research work, the following conclusions were derived:

1. The use of pumice as coarse aggregate:

A. Using the pumice as aggregate to replace natural gravel is a very acceptable choice for producing lightweight concrete that gives the advantage of reducing the dead load of concrete structures.

B. The use of pumice in concrete mixes assists in producing concrete with a dry density that is (41%) lesser, thermal conductivity that is (72.54%) lesser, and (12.5%) higher workability when compared to normal concrete.

2. Lightweight concrete mixes produced using white limestone, red limestone, clay brick wastes, and pumice aggregate have a low thermal conductivity compared to concrete produced from natural gravel.

3. Using lightweight concrete considered one of the greatest means to reduce construction cost and thermal insulation and air-conditioning cost. It also assists in reducing the weight of the structure, which can help to reduce the cost of foundations of the building.
4. White limestone aggregate, red limestone aggregate, and clay brick fragments aggregate can be used as a replacement of gravel when producing lightweight concrete in order to achieve respectable thermal and noise insulation.
5. The absorption capability of lightweight concrete is relatively high when compared to normal concrete. Hence, using this type of concrete is preferred for constructing interior concrete walls (non-structural walls) that are not subjected to or exposed to high humidity percentages.
6. This research assists in emphasizing the available approaches to dispose of the large quantities of stone wastes and clay brick fragments accumulated in the industrial regions that result from cutting, transferring, loading, and unloading stones and brick. Disposing of these wastes will prevent industry regions and the surrounding areas from pollution risks and saves wide areas from being filled up with wastes.

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