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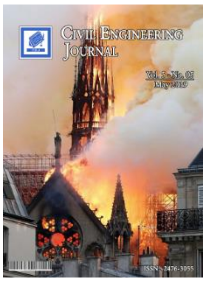

Comparison Mechanical Properties of Two Types of Light Weight Aggregate Concrete

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Abstract

This paper presents the behavior of concrete properties by replacing the conventional coarse aggregate used in the concrete mixture by two types of lightweight aggregate; Expanded Perlite Aggregate (EPA) and Volcanic Pumice (VP). To fulfill this aim; three laboratory tests were applied; density, compressive strength, and abrasion resistance, that conducted to extrapolate the range of the changes in the properties of concrete with existence those types of aggregate in the mixture. Also, the volumetric proportion adopted as a strategy for replacing the coarse aggregate by EPA or VP in the concrete mixture. Then, the volumetric proportion ranged from 10% to 50% with the variation step was 10%. Therefore, ten concrete mixtures are prepared and divided into two groups; each group contains five concrete mixes to represent the volumetric replacement (10-50)% of conventional coarse aggregate by EPA or VP. On the other hand, one extra mixture designed by using conventional aggregate (coarse and fine aggregate) without any inclusion of EPA or VP to be considered as a reference mixture. The obtained laboratory results of this study proved that the density, compressive strength, and abrasion resistance readings of concrete decreased at any volumetric proportion replacement of coarse aggregate by EPA or VP. The decrease in density and compressive strength of concrete readings amounted the peak level at 50% replacing of coarse aggregate by EPA, which were 38.19% and 77.37%, respectively than the reference mixture. Additionally, the compressive strength is an important factor affecting the abrasion resistance of concrete mixture, and loss of abrasion decreased as compressive strength increased.

Keywords: Lightweight Aggregate Concrete; Volumetric Replacement; Density; Compressive Strength; Abrasion Resistance.

1. Introduction

Lightweight Concrete (LWC) is a versatile material that has a great interest and large industrial demand in recent years in a wide range of construction projects, despite its known use dating back over 2000 years. The mineral admixtures, fibers and prolonged age of curing are the effective parameters to control the shrinkage cracking in the LWC [1]. As regards to the economic aspect, the using LWC in the floor slabs would reduce the total costs of the tall buildings through decreasing the foundation volume, the amount of steel reinforcement, and vertical members' cross-sections that saves the used horizontal area [2].

The thermal conductivity of LWC is ranged from 0.2 to 1.0 W/m.K besides the oven dry density range from roughly 300 to not exceed 2000 kg/m^3, with a cubic compressive strength about 1 to more than 60 MPa. These ranges could

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compare to those for normal weight concrete with 1.6 to 1.9 W/m.K, roughly 2100 to 2500 kg/m^3, and 15 to greater than 100 MPa [3].

Alshihri et al. [4] pointed out that the LWC could employ for rapid evolution in construction applications of high rise buildings larger-sized and long-span concrete structures. According to Neville and Brooks [5], there are three kinds of LWC: the first kind through substitution the normal weight aggregate by lightweight aggregate of low specific gravity (lower than 2.6) and this kind of concrete is well known as lightweight aggregate concrete. The second kind inducing bubble voids within the concrete or mortar mass, the concrete is known as aerated, cellular, foamed, or gas concrete. Through eliminating the fine aggregate from the mix, this is considered as the last kind of LWC; and it is known as no-fines concrete. Li [6] concluded the structural lightweight concrete status achieved when the concrete has a compressive strength more than 17 MPa with a bulk density less than 1950 kg/m^3. Furthermore, Vilches et al. [7] classified the LWC into three groups based on their use and physical properties (for structural use, for both structural/insulating purpose and for insulating).

Jedidi et al. [8] studied the influences of replacement sand by EPA on the compressive strength and thermo-physical properties of LWC at different ages. The researchers indicated that the compressive strength decreased when the perlite dosage increased, but on the other hand, the existence EPA improved the thermal resistance of concrete.

Yu et al. [9] designed an ultra-LWC that could enhance both thermal insulation and the load bearing element from lightweight and binder aggregates. They referred to that the excellent thermal characteristics achieved with a thermal conductivity of approximately 0.12 W/m.K; and at the age of 28 days, the compressive strength ranged from 10 to 12 N/mm^2. Through using the extrusion strategy by Lu et al. [10], the magnesium oxchloride cement with the expanded perlite/paraffin composite has a significant impact on developing the energy storage capacity in buildings. Depending on the study submitted by Różycka and Pichór [11], the use expanded perlite waste in autoclaved aerated concrete has a positive effect on the formation of calcium silicate hydrates. To increase the compressive strength of concrete, El Mir and Nehme [12] included the waste perlite powder in the self-compacting concrete mixtures as a filler material.

The natural lightweight aggregates such as pumice, diatomite, scoria, volcanic cinders, tuff, also artificial lightweight aggregates such as perlite, expanded clay, slate, shale, and vermiculite have employed as construction substances [13].

Kurt et al. [14] noticed that when the pumice proportion increased caused to increase the segregation tendency in fresh concrete. By using the pumice as lightweight aggregate, and different ratios of blast furnace slag and water/(cement and mineral additive); Kurt et al. [15] studied the mechanical and physical characteristics of self-compacting lightweight aggregate concrete. It observed that when the ratio of blast-furnace slag is constant and the increase in the amount of pumice aggregate; the unit weights decreased and the water absorption ratios increased. The lightweight concrete with pumice and tragacanth additive can be employed as dividing and coating material in the constructions due to its insulating features [16]. Wijatmiko et al. [17] pointed out that the use coated pumice in the concrete mixture caused to increase the flexural strength of beam by 2.58% as compared to uncoated ones. Numan et al. [18] used volcanic pumice as an alternative material to the total volume of crushed coarse or sand in the concrete mixture. They deduced that the replacement volcanic pumice instead of fine aggregate exhibited less impact resistance than the replacement of volcanic pumice instead of coarse aggregate.

Numan [19] added a super-plasticizer and Glenium 51 as additives substances to the concrete mixture to rise from the compressive resistance of concrete. The treatment pumice aggregate by sodium hypochlorite solution has a significant impact on increasing the compressive strength of concrete [20]. Cemalgil and Onat [21] investigated the effect of using waste marble aggregate and waste demolition materials in the concrete mixture on the engineering properties of concrete. They found that when using demolition waste the abrasion resistance of concrete significantly decreased. Karataş et al. [22] detected that the increment dose of the lightweight aggregate (expanded perlite and pumice) would decrease the tensile strength in bending and compressive strengths of mortar specimens subjected to high temperatures. On the other hand, to minimize the impact waste on the environment, besides improving the mechanical properties and fire resistance of construction material; Yaseen et al. [23] reused plastic waste resulting from mineral water bottles as a different adding ratio to gypsum mixture. They disclosed that the addition 1% of plastic waste resulted in increasing of the compressive strength and modulus of rupture of gypsum by 18.75% and 26.32%, respectively; while adding 1.5% resulted in enhancing the fire resistance of gypsum.

Different studies were conducted to develop the structural action and sustainability of reinforced concrete members through using or inserting a green material on or throughout their, such as Kadhim et al. [24]. The scholars conducted a numerical analysis to evaluate the structural action of reinforced concrete by externally wrapping it with basalt fiber-reinforced polymer. They detected that the ultimate load was increased by 14.8% in spite of 20% corrosion in the flexural steel rebar under eight layers of basalt fiber-reinforced polymer composite.

Based on the presented literature survey and besides to search the best of the authors' knowledge, it is found that the studies interesting to emulate the abrasion resistance of concrete with existence EPA and VP materials are indeed scarce. Also, for more highlight on the trend and behavior of the relationship between the compressive strength and abrasion resistance of concrete under different volumetric ratios of replacing traditional coarse aggregate by these materials. Consequently, the experimental program is presented to clarify the target relation and emulate the influences of existence EPA and VP in the concrete mixture on the physical-structural response of concrete.

2. Research Methodology

In this paper, the experimental work accomplished to emulate the influence of addition two types of lightweight material; EPA or VP on the changing properties of concrete. The volumetric ratio strategy was adopted to add these materials instead of coarse aggregate in the mixture. The volumetric ratio was 10, 20, 30, 40, and 50%, respectively.

The essential objective of this paper is to specify the variance between properties of concrete with the presence EPA once and other times with presence VP in the concrete mixture. Moreover, the properties of concrete that contained EPA or VP as an additive material compared to the properties of concrete without any addition to specifying the real amount of changing of the physical-structural demeanor of concrete. To achieve this objective; eleven laboratory concrete mixtures prepared and undergone to (density, compressive strength, and abrasion resistance) test. It is worth noting that in the lab of Building and Construction Technology Engineering/Northern Technical University in Mosul/Iraq, the mixing of concrete, preparation of specimens, as well as, material (the main ingredient of concrete) and specimen tests done.

3. Materials' Specifications

The specifications and characteristics of the materials used in this work are clarified in the following subsection:

3.1. Cement

The Ordinary Portland Cement (OPC-Type1) that produced from Badoosh Cement Factory used. The physical, mechanical, and chemical characteristics of the cement used, besides to the cement limitations based on Iraqi Organization for Standards and Specifications (IQS, No. 5,1984) [25] are given in Table 1 and 2, respectively. From these tables, it observed the characteristics of cement used within the range of the Iraqi Organization for Standards and Specifications (IQS, No. 5, 1984) [25].

Table 1. Physical and mechanical characteristics of cement

Characteristics	Test results of cement used	IQS, No.5,1984 [25]
Specific surface area, Blaine method, cm^2/gm.	2800	≥ 2300 cm^2/gm.
Standard consistency, %	27.5	----
Setting time, Vicat's method		
Initial setting, min.	137	≥ 45 minutes
Final setting, min	165	≤ 600 minutes
Fineness on sieve No. 170, %	3	≤ 22%
Compressive strength of 50 mm cubic mortar samples, N/mm^2		
3 days	23.8	>15 N/mm^2
7 days	29.6	>23 N/mm^2
Tensile strength, N/mm^2		
3 days	1.63	>1.6 N/mm^2
7 days	2.48	>2.4 N/mm^2

Table 2. Chemical analysis of cement

Compound composition	(%) cement used	IQS, No.5, 1984 [25] (%)
Al_2O_3	5.80	3.0–8.0
SiO_2	21.35	17.0–25.0
Fe_2O_3	2.60	0.5–6.0
CaO	62.30	60.0–67.0
SO_3	2.50	2.5–2.8
MgO	3.33	Not more than 5%
C_3S	34.50	31.3–41.05
C_2S	28.00	28.61–37.9
C_3A	10.20	11.96–12.3
C_4AF	7.82	7.72–8.02

3.2. Coarse Aggregate

The washed coarse aggregate used that gathered from Mosul city. It was rounded and with a maximum size of 12.5 mm. The findings of the sieve analysis of coarse aggregate used illustrated in Table 3. As shown in Table 3, the accumulated percentage passing of coarse aggregate used conformed to British Standard (BS: 882, 1992) [26], within the Limit 5-14 mm (Fine) specification. On the other hand, the specific gravity and absorption capacity of the coarse aggregate used was 2.66 and 0.4%, respectively.

Table 3. Sieve analysis of coarse aggregate used and specification of BS:882, 1992 [26]

Sieve size (mm)	Accumulated percentage retained (%)	Accumulated percentage passing (%)	BS: 882,1992 specification [26]		
			5-14 mm (Fine)	5-20 mm (Medium)	5-40 mm (Coarse)
14	0.0	100	90–100	40–80	25–55
10	15.70	84.30	50–85	30–60	10–40
4.75	91.40	8.60	0–10	0–10	0–5
2.36	100	0.0	----	----	----

3.3. Fine Aggregate

The rounded natural sand with a maximum size 4.75 mm collected from Khazer region in Mosul /Iraq used in all concrete admixtures as a fine aggregate. Also, the sieve analysis conducted on the sand used. The outcomes of sieve analysis for the sand used depicted in Table 4. From this Table, it disclosed that the accumulated percentage passing of the sand used was within the range of BS: 882, 1992 [26] under the fine limitations. The specific gravity, absorption capacity, and material finer than sieve No. 200 of the sand used were 2.68, 2.88%, and 0.8%, respectively.

Table 4. Sieve analysis of fine aggregate used and specification of BS: 882, 1992 [26]

Sieve size (mm)	Accumulated percentage retained (%)	Accumulated percentage passing (%)	BS:882,1992 specification [26]			
			Limits	(Fine)	(Medium)	(Coarse)
4.75	0.0	100	89 – 100	-	-	-
2.36	11.0	89.0	60 – 100	80 – 100	65 – 100	60 – 100
1.18	25.5	74.5	30 – 100	70 – 100	45 – 100	30 – 90
0.60	44.5	55.5	15 – 100	55 – 100	35 – 80	15 – 45
0.30	78.5	21.5	5 – 70	5 – 70	5 – 48	5 – 40
0.015	96.5	3.5	0 – 15	----	----	----

3.4. Expanded Perlite Aggregate (EPA)

Expanded perlite is a glassy volcanic rock, honey-comb like or bubble-like, white or grayish-white granules as shown in Figure 1. It has some advantages such as good performance in low temperature, light weight, incombustibility, better chemical stability, easy application, and corrosion resistance. In construction, the perlite considered good thermal insulation and also sound-absorbing products. The thermal conductivity of perlite within the range of 0.06 to 0.17 W/m. K under high temperatures and of 85 kg/m³ density [27].

Figure 1. Expanded Perlite used

3.5. Volcanic pumice (VP)

From Hatay region/Turkey, the Volcanic Pumice (VP) collected that used as an alternative material to gravel in concrete mixtures. It is an aggregate with light gray colored coarse aggregate, as shown in Figure 2. Due to the VP used has a low density (835 kg/m^3); therefore it can float on the water. The VP consists of different chemical compounds, the percentage of main these compounds depicted in Table 5 based on Saad [28].

Figure 2. The volcanic pumice used

Table 5. Chemical composition of volcanic pumice

Compound	Percentage of VP
Cao	14.1
SiO_2	49.5
Al_2O_3	16.4
Fe_2O_3	14.7
MgO	1.9
SO_3	0.2
K_2O	1.3
Na_2O	0.1

3.6. Silica Fume

The silica fume (SikaFume-HR) that manufactured by Sika Near East s.a.l Beirut-Lebanon with fineness 0.1µm is used. The technical data of SikaFume-HR collected and illustrated in Table 6 based on information from product factory. The aim of using silica fume is to improve the strength of concrete, which may be ascribed to the pozzolanic reaction $Ca(OH)_2$ crystals located in the transition zone. As a result, it will enhance the bond between the cement particles and aggregate surface.

Table 6. Technical data of SikaFume-HR

Property	Result
Composition	A latently hydraulic blend of active ingredient
Appearance	Grey powder
Dry bulk density	0.05 – 0.1 kg
Dosage	2–10% by weight of cement

3.7. Chemical Admixtures

Super-plasticizer (Sika ViscoCrete-SF 18) used as high range water, minimizing admixture and viscosity modifying agent. The used potion was 1% by weight of cement. The characteristics of super-plasticizer used, as provided by the manufacturer, are illustrated in Table 7 [29].

Table7. The characteristics of super-plasticizer used

Property	Sika ViscoCrete-SF 18
Chemical base	Modified poly carboxylates based polymer
Appearance / color	Light brownish liquid
pH value	3 – 7
Density	1.1 g/cm^3 ± 0.02, (at + 20 ºC)
Dosage	1.0 - 2.0% by weight of cement

3.8. Water

In this paper, all concrete mixtures and curing process of samples done by using ordinary water from the tap without any additives and treatment.

4. Method of Mixing and Preparation of Specimens

The drum mixer with a capacity of 0.071 m^3 was used to pour all batches of concrete. Each batch was used to cast the six iron cube specimens of (100×100×100) mm, and six iron cylinder specimens of (150×75) mm to perform the compressive strength, and abrasion resistance tests. All molds are cleaned and oiled their interior surface before using them.

Table 8 shows all details the mix design proportions of the reference concrete mixture (C1). The reference concrete mixture was prepared depending on recommendations of the American Concrete Institute (ACI 211.1-91, 1991) [30] to attain a compressive strength of concrete not less than 28 MPa.

To obtain the structural response of concrete under replacement conventional coarse aggregate by EPA or VP materials; ten concrete mixtures prepared besides the reference mixture. The volumetric ratio method was adopted to illustrate the replacement technique of coarse aggregate by these materials (the volumetric ratio ranged from 10% to 50%). The C2, C3, C4, C5, and C6 represent the concrete mixtures under replacement technique of conventional coarse aggregate by EPA with the variable step of 10%, while C7, C8, C9, C10, and C11 represent the concrete mixtures under replacement technique of conventional coarse aggregate by the VP with also variable step of 10%.

It is worth to mention that the current replacement technique adopted by removing a ratio of coarse aggregate and substituted by an equivalent ratio of EPA or VP only, while the other constituent proportions of the reference concrete mixture were kept constant. Table 9 depicts the concrete mix proportions of all mixtures designed. As a more clarified the current replacement technique; some calculations inserted at the end of Table 9. All specimens immersed in curing tank at 23°C and relative humidity more than 90% till testing at the age of 28 days. Figure 3a and 3b depicts some specimens after the expiry of the curing period.

Table 8. Mix Proportion of Concrete Constituents

Constituents	Water	Cement	Sand	Gravel
Weights (kg/m³)	175	350	652.5	1176.5
Percentages (%)	0.5	1	1.864	3.361

Table 9. Compositions of Mixes

Mixture designation	Water (kg/m³)	Cement (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	Perlite		Pumice	
					%	(kg/m³)	%	(kg/m³)
Mix C1	175	350	652.5	1176.5	0	0	0	0
Mix C2	175	350	652.5	1058.85*	10	3.85**	0	0
Mix C3	175	350	652.5	941.20	20	7.70	0	0
Mix C4	175	350	652.5	823.55	30	11.55	0	0
Mix C5	175	350	652.5	705.90	40	15.40	0	0
Mix C6	175	350	652.5	588.25	50	19.25	0	0
Mix C7	175	350	652.5	1058.85	0	0	10	37.78***
Mix C8	175	350	652.5	941.20	0	0	20	75.57
Mix C9	175	350	652.5	823.55	0	0	30	113.35
Mix C10	175	350	652.5	705.90	0	0	40	151.14
Mix C11	175	350	652.5	588.25	0	0	50	188.92

* Gravel in C2 = (1176.5 – (0.1 × 1176.5)) = 1058.85
** Perlite in C2 = ((0.1× 1176.5)/2.6)× 0.085 = 3.85
*** Perlite in C7= ((0.1× 1176.5)/2.6)× 0. 835 = 37.78
Unit weight of used aggregate = 2.6
Unit weight of used Pumice = 0.835
Unit weight of used Perlite = 0.085

(a) **(b)**

Figure 3. Specimens with different percentage of volumetric replacement (a) Cubic, (b) Cylindrical

5. Tests of Specimens

The laboratory tests are divided into two stages depending on the status of concrete. With fresh concrete status, the densities for all concrete mixtures are tested and considered the first stage of tests. On the other hand, the second stage of tests began when the concrete achieved hardened status (at the age of 28 days). At this stage, both the compressive strength and abrasion resistance tests for all prepared specimens accomplished.

5.1. Fresh Density Test

According to the American Society for Testing and Materials (ASTM C138/C138M-01a, 2001) [31] specifications; all fresh concrete mixtures density examined. The density value is calculated through determining the net weight of freshly mixed concrete and divided by the volume of concrete produced from a mixture at the moment of casting.

5.2. Hardened Concrete Tests

5.2.1. Compressive Strength Test

When the cube specimens reached the age of 28 days, they subjected to the compressive strength testing. This test carried out by using the Uniaxial Testing Machine (UTM) of capacity 2000 kN, at the rate of loading of 0.5 MPa/s and it comforted to specifications of BS 1881: Part 116, 1983 [32]. Figure 4 illustrates the UTM and cube specimen which is ready to test.

Figure 4. The cube specimen in the UTM mm

5.2.2. Abrasion Resistance Test

To give a real allusion of the relative abrasion resistance of concrete based on testing of currently fabricated specimens, the abrasion resistance test conducted on the cylindrical specimens. The age of these specimens was 28 days. The test apparatus composes of rotating cutter and drill press. All the steps that conducted to fulfill the abrasion resistance test conformed to the recommendations of ASTM C944/C944M-12, 2012 [33]. These steps summarized as follows:

- The mass of the specimen was determined to the nearest 0.1 grams.
- The rotating cutter device mounted in the drill press shaft.
- When the electric motor is turned on, the cutter lowered slowly until being in contact with the surface of the concrete specimen. Then, the abrasion process started of normal load (roughly10 kg) on the surface specimen for two continuous minutes. At the end of two minutes; the specimen removed from the rotating cutter, cleaned the surfaces from debris using a soft brush, and weighed specimen. These actions repeated with the same time interval (two minutes) with the minimum test schedule shall involve three 2-min periods carried on three separate areas of the concrete surfaces. The test stopped when the weight of the specimen stabilizes or 1.0 mm (depth of wear); whichever happened first. Figure 5 shows the conducted abrasion resistance test by using the rotating cutter drill press and the balance scale.

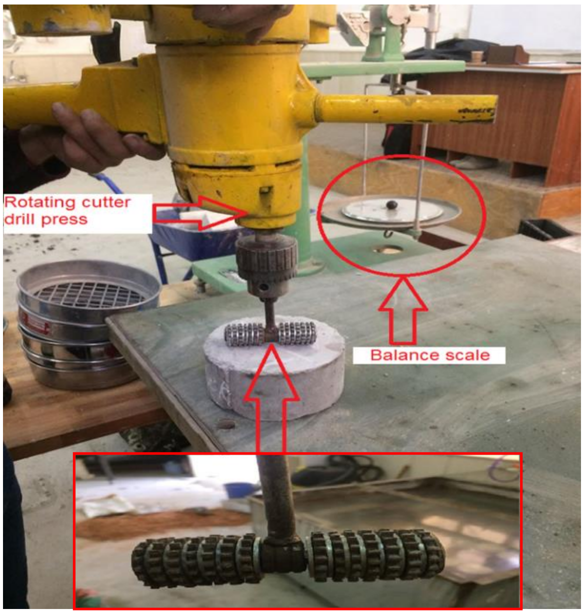

Figure 5. The specimen under the rotating cutter drill press

6. Results and Discussion

6.1. Fresh Properties Results

Under all designed composition systems of concrete mixtures; the findings of the unit weight test are clearly illustrated in Table 10 and Figure 6, respectively. In Table 10 NWC denotes to Normal Weight Concrete, while LWAC denotes to Light Weight Aggregate Concrete.

Table 10. Results of density for all concrete mixes designed

Mixture designation	EPA%	VP%	Density (kg/m³)	Type of concrete
Mix C1	0	0	2435	NWC
Mix C2	10	0	2100	NWC
Mix C3	20	0	1865	LWAC
Mix C4	30	0	1695	LWAC
Mix C5	40	0	1565	LWAC
Mix C6	50	0	1505	LWAC
Mix C7	0	10	2145	NWC
Mix C8	0	20	1960	LWAC
Mix C9	0	30	1925	LWAC
Mix C10	0	40	1895	LWAC
Mix C11	0	50	1845	LWAC

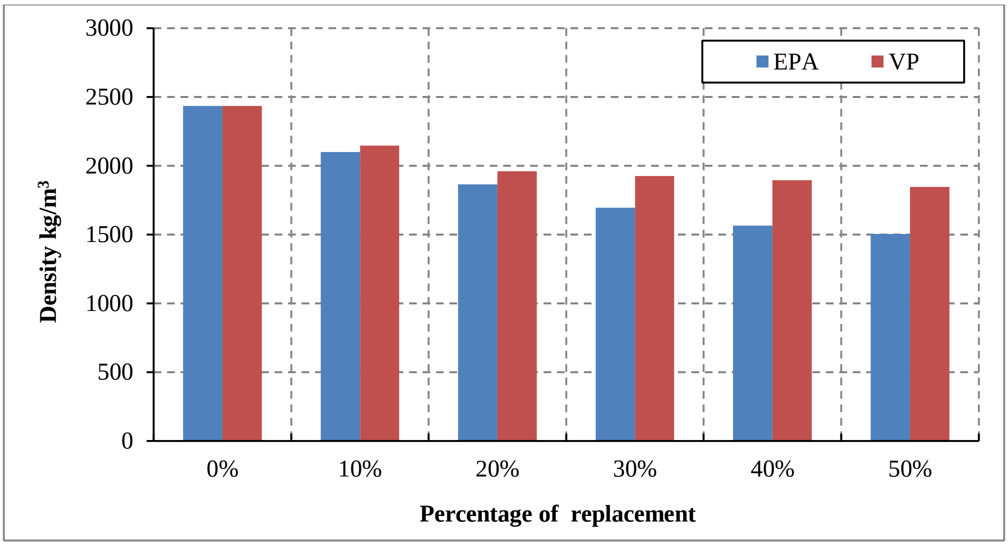

Figure 6. Fresh density for each mix

As shown in Table 10 and Figure 6, the value of density in C2 and C7 is not much affected as compared to the reference mixture, where the decrease in C2 and C7 density was 13.75% and 11.91%, respectively than C1. On the other hand, the density value of C2 and C7 stilled within the range of NWC (2000-2500) kg/m^3. Therefore, the impact of replacing 10% coarse aggregate by (EPA or VP material) in the concrete mixture is considered somewhat limited.

As it is evident in Table 10 and Figure 6, the kind of concrete automatically turned to normal to lightweight (the density of lightweight concrete less than 2000 kg/m^3) when increasing the percentage dosage of EPA or VP more than 10%. However, the incremental dose of EPA in the concrete mixture by (20, 30, 40, and 50) % in (C3, C4, C5, and C6) accompanied in decreasing the concrete density of (23.41, 30.39, 35.73, 38.19) % compared to the reference mixture. Additionally, the concrete density decreased as (19.51, 20.94, 22.18, and 24.23%) when transforming from the reference mixture to C7, C8, C9, C10, and C11, respectively. The decrease in the density of concrete when replacing coarse aggregate by EPA or VP materials are considered logically due to these materials have the lowest density values than the conventional coarse aggregate.

Another note recorded on the results in Table 10 and Figure 6 that is the replacement of coarse aggregate by EPA in the concrete mixture was more impact on the reducing density than to the replacement VP under the same level of volumetric ratio proposed. This because of the lower density of EPA as compared with the VP density.

6.2. Compressive Strength Test Results

At 28 days age of cubic specimens for all designed mix proportions of concrete, the compressive strength test conducted. The outcomes of this test are illustrated in Table 11 and Figure 7, respectively.

Table 11. Compressive strength of composition mixes

Mixture designation	EPA%	VP%	Compressive Strength (MPa)
Mix C1	0	0	28.50
Mix C2	10	0	21.85
Mix C3	20	0	16.50
Mix C4	30	0	12.70
Mix C5	40	0	9.00
Mix C6	50	0	6.45
Mix C7	0	10	25.50
Mix C8	0	20	22.95
Mix C9	0	30	20.85
Mix C10	0	40	19.35
Mix C11	0	50	17.85

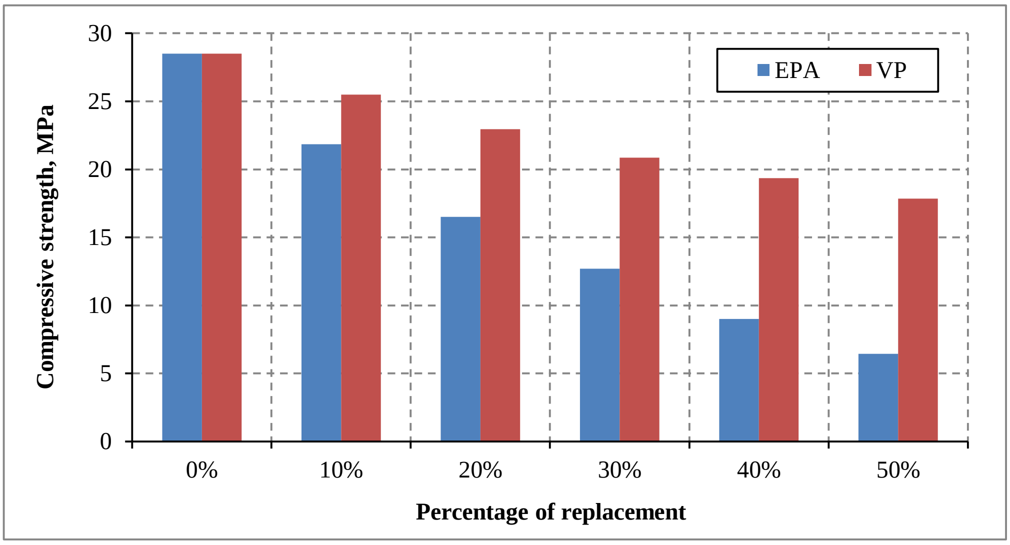

Figure 7. Compressive Strength for each mix

From the results in Table 11 and Figure 7, the maximum value of compressive strength recorded in C1 (without any percentage of replacement the conventional coarse aggregate by EPA or VP material) as compared to the other mixtures. The value of compressive strength in C1 is decreased by (23.33, 42.11, 55.43, 68.42, and 77.37)% when approached to C2, C3, C4, C5, and C6, respectively. Furthermore, the value of compressive strength of C1 decreased by (10.53, 19.47, 26.84, 32.11, and 37.37)% when approached to C7, C8, C9, C10, and C11, respectively. The inclusion EPA or VP material within the concrete mixture working to reduce the level of bonding between constituents of the concrete and increasing in the porosity level of the specimen simultaneously. For these reasons interpreted why the compressive strength value reduced in C2, C3, C4, C5, C6, C7, C8, C9, C10, and C11 as compared to the C1.

A closer look at the percentage results that are mentioned above in this section, it is found that the lowest percentage of decreasing in compressive strength of concrete occurred between C1 and C7, which was 10.53%. This result can aid the engineers to capture the compressive strength of concrete not much affected when the dosage of VP was 10% in the mix, and hence can be used mixture designed in C7 in some concrete applications with acceptable compressive strength.

The findings in Table 11 and Figure 7 demonstrate that the influence of adding EPA as an alternative substance to coarse aggregate was more effective from decreasing the compressive strength of concrete than the VP. This attributable is weak mechanical properties (especially compressive resistance) of the EPA material compared to VP material.

6.3. Abrasion Test Results

All the results gathered from the abrasion test in the current work inserted in Table 12, Figure 8, and Figure 9, respectively.

Table 12. Abrasion test results for each mixture designation

Mixture designation	Depth of wear (mm)	Abraded materials (gm.)
Mix C1	0.355	14.80
Mix C2	0.44	18.15
Mix C3	0.505	21.50
Mix C4	0.56	25.00
Mix C5	0.625	28.50
Mix C6	0.68	32.00
Mix C7	0.38	15.55
Mix C8	0.423	17.37
Mix C9	0.465	19.12
Mix C10	0.501	20.60
Mix C11	0.542	22.34

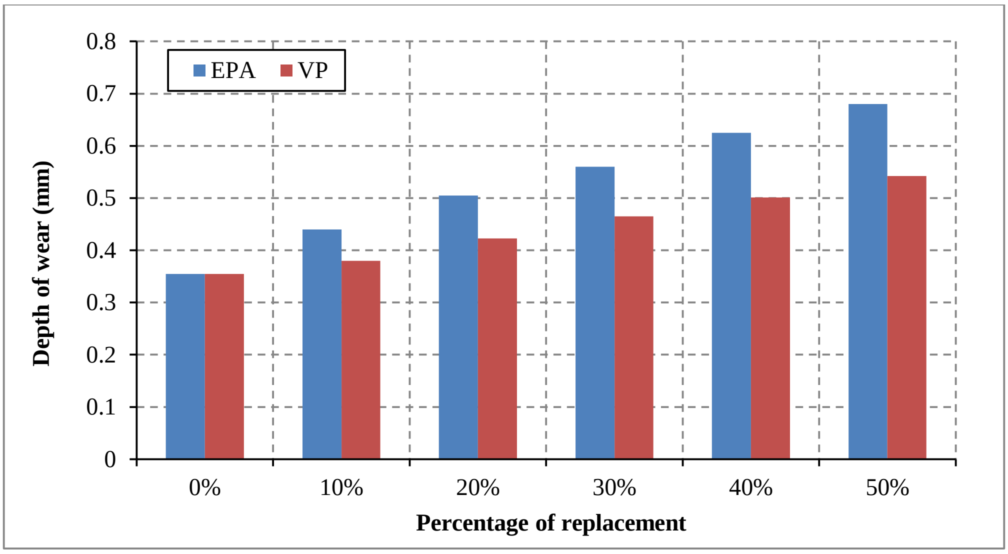

Figure 8. Depth of wear for each mix

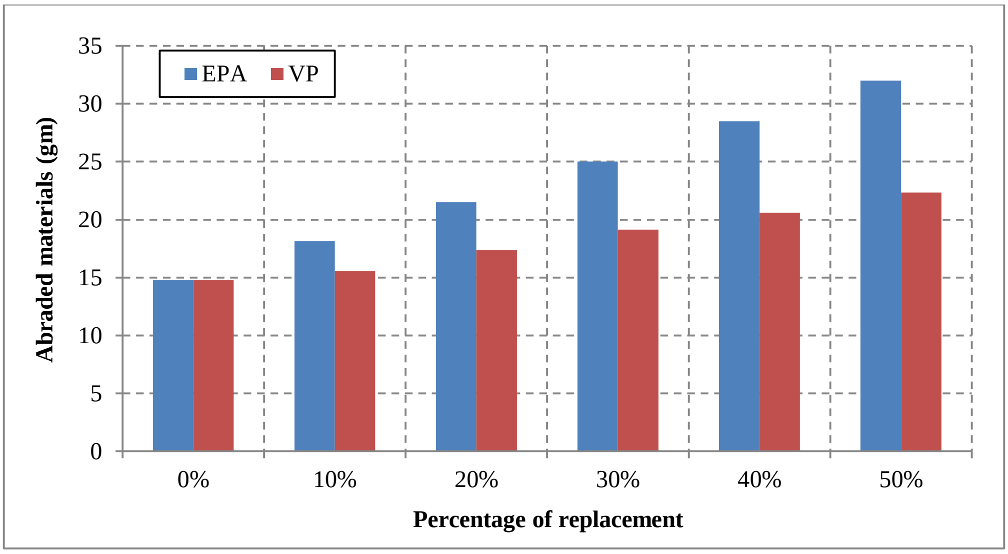

Figure 9. Abraded materials for each mix

As clearly shown in Table 12, Figure 8, and Figure 9 that the lowest depth of wear and abraded materials values recorded on the reference mixture, which was 0.335 mm, and 14.8 gm., respectively. The increment of replacement conventional coarse aggregate by EPA in C2, C3, C4, C5, C6 accompanied by the increasing in depth of wear by (23.94, 42.25, 57.75, 76,06, 91.54)% and also increase the abraded materials by (22.64, 45.27, 68.92, 92.57, 116.22)% as compared with C1. Additionally, the increment of VP dosage as replacement material instead of coarse aggregate in concrete mix as (10, 20, 30, 40, and 50)% caused to increase the depth of wear by (13.43, 26.27, 38.81, 49.55, 61.79)% and also increase the abraded materials by (4.73, 17.36, 2919, 93.19, 50.95)% as compared with C1. The reason for increasing the depth of wear and abraded materials weights in the specimens is due to its contained either EPA or VP because of the low bonding achieved between the constituents of concrete and increased the porous for those specimens.

At the same volumetric proportion of replacement, the specimens with VP exhibited more strength to abrasion than those contained EPA as shown in Table 12, Figure 8, and Figure 9. These back that the total porosity of VP is relatively lower than the EPA, as well as, the compressive resistance of EPA is lower than the VP. The same reasons explain why the less abrasion resistance recorded at C6 that contain the highest volumetric proportion of EPA replacement to the total volume of conventional aggregate. Furthermore, the tendency of decreasing both compressive and abrasion resistance of specimens with increasing the EPA dosage in the concrete mixture was significant as compared to increase VP dosage.

Through the comparison of the results in Tables 11 and 12, it found that the inverse correlation achieved between compressive strength and abrasion resistance of concrete with any percentage dose of EPA or VP in the mixture.

For more visualization about the steps that carried out in this work, Figure 10 illustrates these steps as a flowchart.

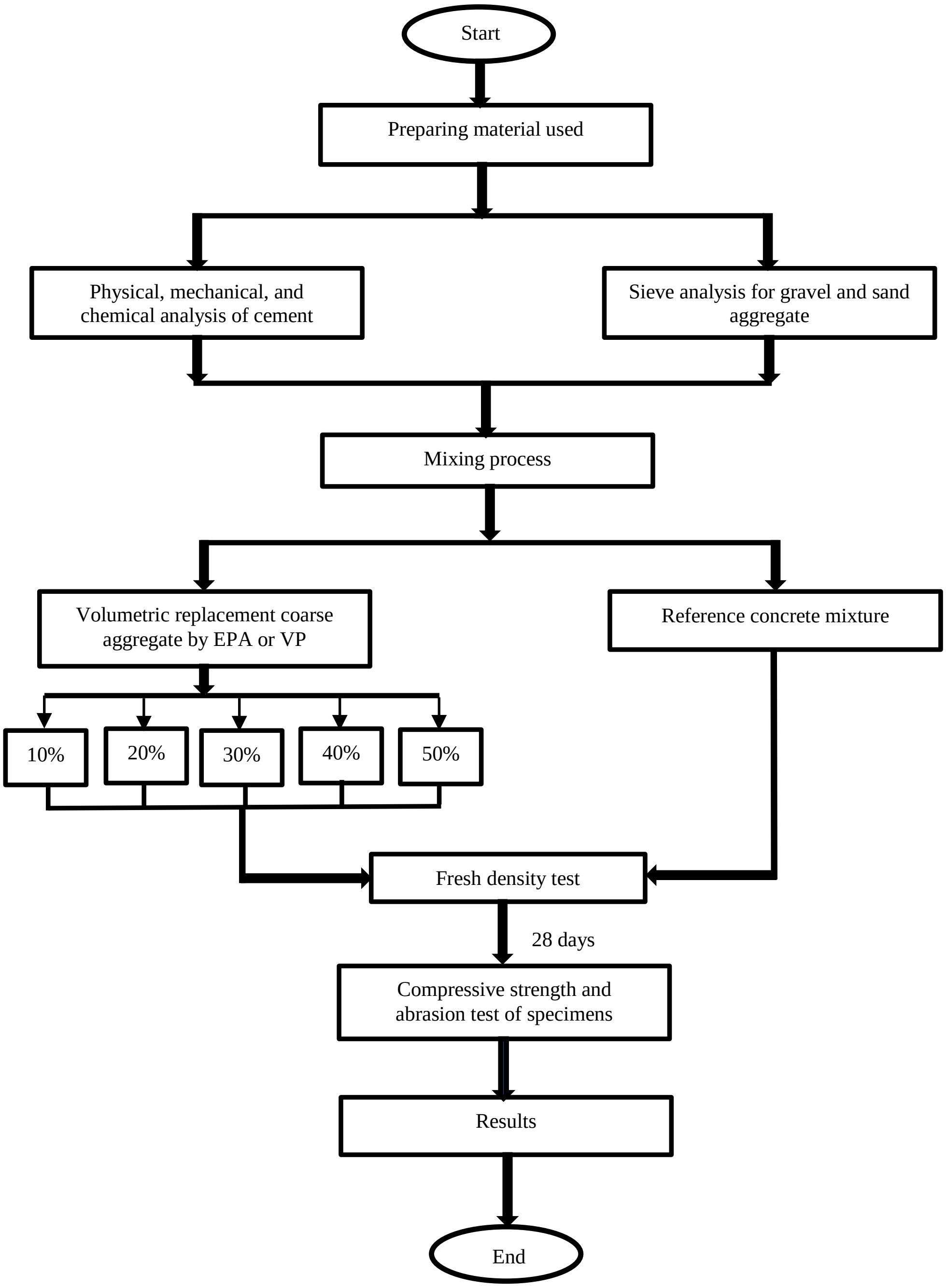

Figure 10. Flow chart of the overall process in this work

7. Conclusions

Based on the present experimental outcomes in this article; the main conclusions can be summarized as follows:

- The increment of EPA dosage in the concrete mixture from 10 to 50% with a variation step was 10% contributes to the decrease the concrete density from 13.75 to 38.19% as compared with reference mixture. With the same variation step of increment; but using VP material, the range of decreasing the concrete density of 11.91 to 24.23% as compared to the reference mixture. Accordingly, the presence EPA in the concrete mix was a higher impact to decrease concrete density than VP.
- Under the maximum percentage of volumetric replacement coarse aggregate by VP material (50%), the decrease in the compressive strength of C11 did not exceed 37.37%, while under only 20% of volumetric replacement coarse aggregate by EPA (C3) the compressive strength decreased by 42.11% compared to reference mixture. Therefore, the influence of adding a VP as an alternative substance to coarse aggregate was less effective in the decrease compressive strength of concrete than the EPA.
- The trend of increasing both of depth of wear and abraded materials value was more with existence EPA within the concrete mixture than VP. Therefore, the specimen contains VP exhibited more resistance to abrasion than the

EPA. The highest depth of wear and abraded materials values achieved in C6 (with the highest percentage dosage of EPA) and was 0.68 mm, 32 gm., respectively.

- A closer look at the findings obtained from this work illustrates that the compressive strength is an important parameter affecting abrasion strength of the concrete mixture. Loss of abrasion decreased as the compressive strength increased.

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9. Conflicts of Interest

The authors declare no conflict of interest.

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