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EXPERIMENTAL INVESTIGATION ON STRUCTURAL LIGHTWEIGHT AGGREGATE CONCRETE USING PALM-OIL CLINKER AND EXPANDED PERLITE AGGREGATES

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Abstract

Lightweight concrete produced by utilizing waste materials has the benefit of protecting the environment and reducing the cost in construction industry. Palm Oil Clinker (POC) aggregate considered as a lightweight aggregate due to its lower bulk density and porous nature compared to normal weight aggregate. Which lead to a high Aggregate Crushing Value (ACV) of (POC) coarse aggregate that cause a reduction in strength. In this paper, Palm Oil Clinker (POC) and Expanded Perlite Aggregate (EPA) were used as a fine and coarse aggregate in the production of structural lightweight concrete. The aim of the study is to improve the strength of (POC) lightweight concrete by partially replacing (POC) coarse aggregate with Normal Coarse Aggregate (NCA). Then, introducing (EPA) by partially replacing it with (POC) fine aggregate to reduce the density. Department of Environment method (DOE) was used to design the control mix of normal concrete grade 40. Absolute volume method was used for different replacements of (POC) and (EPA) aggregates. Three phases of mixes were conducted. First phase is considered as the control phase with normal weight concrete mix and (POC) lightweight concrete mix with 100% of fine and coarse (POC) aggregate. Second phase consist of partially replacement of (POC) coarse aggregate with (NCA) in different percentages. Third phase is done by replacing (POC) fine aggregate with (EPA) in the optimum mix from the second phase. Density, strength and quality of the concrete mixes were tested for 7 and 28 days only. No tests on 14 days conducted because the difference in strength gained in 14 and 28 days is only 9%. In summary, replacing 10% of (POC) coarse aggregate with (NCA) made a significant increase in the strength from 27.7 MPa to 35.49 Mpa. Also, by replacing (POC) fine aggregate with EPA made a reduction in density from 1900 kg/m^3 to 1847 kg/m^3.

Keywords: Compressive strength, Density, Expanded perlite aggregate, Lightweight aggregate concrete, Palm-Oil Clinker, UPV.

1. Introduction

The building industry is probably the biggest one in the world. Nowadays, the development rate of this industry is rapidly increasing around the world, specifically in developing countries because of its noticeable industrial and economic development of infrastructure and way of living [1].

Concrete is considered as the main construction material used in building industry due to its ability to be formed in many different sizes and shapes, strength and durability to withstand the harshest environmental conditions [2]. In a comparison with other building materials such as wood, steel and aluminium, the worldwide consumption of concrete is twice the total consumption of these materials. As reported by Meyer [3], the total annual production of concrete around the world is 10 billion tonnes.

Concrete is categorized based on density into three different types namely Heavy-Weight Concrete (HWC), Normal-Weight Concrete (NWC) and Light-Weight Concrete (LWC). (LWC) is considered the most attractive type of concrete due to its high strength and low density compared to the other types. It was reported that (LWC) can be produced with a range of 300-2000 kg/m^3 of oven dry density and a cube compressive strength from 1 to above 60 MPa. This reduction in density compared to (NWC) will lead to reduce the dead weight of the reinforced structural elements such as columns, beams, slabs and foundations [4]. According to Neville [5], the compressive strength of structural lightweight should be more than 17 MPa. (LWC) can enhance the buildings structural efficiency as it has better thermal performance, which may lead to a considerable reduction in the consumption of energy in buildings [6].

Today, it is more important than ever to use environmentally friendly and energy-saving materials. The use of by-product and solid waste in construction has attracted the attention of many researchers due to many factors such as increasing of the cost of raw materials and natural resource depletion [7]. In addition, huge amount of waste produced from the continuous development of the technological and industrial fields and subsequent disposal of this waste in dump sites has led to hazards and environmental pollution [8].

So, in order to protect the environment, it is necessary to eliminate or reduce these wastes. The best way to achieve this is by recovering the usable materials from the wastes and utilizing these wastes as a raw material. To apply this approach, researches should be done on the existing products and how to replace the waste generated by these products, such as replacing the aggregate by these wastes in the production of concrete [9].

Palm-Oil Clinker (POC) is a waste material produced by the incineration process at the palm oil mill. This process requires the use of palm oil shell and fibres with an estimated ratio in order to generate electricity. Both materials, palm oil shell and fibres, are moved to the boiler where the process of incineration takes place using conveyor belt. Then both materials are burned at a temperature around 850 °C to generate the steam by heating the water. Due to this incineration, the (POC) will be produced [10]. (POC) can be obtained from the palm oil mill and has a size ranging from 150 mm to 200 mm. (POC) has physical properties such as having grey colour, porous structure and rough edges.

The strength properties of (POC) were investigated by Zakaria [11]. The results showed that the bulk densities of oven dry samples of coarse and fine (POC) aggregate were 815 kg/m^3 and 1075 kg/m^3, respectively. From these results, fine and coarse (POC) aggregate is categorized as lightweight aggregate, which is according to BS EN 13055-1:2003 [12] that classified the bulk density of oven dry lightweight aggregate to be less than 960 kg/m^3 and 1200 kg/m^3 for coarse and fine aggregate, respectively. Also, the specific gravity of coarse and fine (POC) found to be within the range of 1.7 to 1.95.

Using lightweight coarse aggregate by full replacement will lead to a significant reduction in density due to its porous nature and strength due to the high (ACV) of lightweight coarse aggregate. Kanadasan and Razak [13] reported that the more replacement of (POC) coarse aggregate, the more reduction in density and strength. In a study conducted by Abutaha et al. [14], (POC) was utilized as a replacement of fine and coarse aggregate to investigate its effect on the strength of concrete. 30.37% reduction in strength compared to the control mix when (POC) used as coarse aggregate with 100% replacement. On the other hand, when (POC) replaced with Normal Fine Aggregate (NFA) only with different percentages, it gained almost the same strength with a negligible reduction in density with 100% replacement. Ibrahim et al. [15] studied the effect of using (POC) coarse aggregate with different levels of replacement on pervious concrete with different methods of curing. The results showed that the highest rate of reduction in all curing methods was by utilizing 100% replacement of (POC) coarse aggregate.

Expanded perlite aggregate (EPA) is a volcanic glass consist of silica and under a high heat its volume can be significantly expanded. At a temperature of 900 ºC to 1100 ºC, the chemical water within the perlite particles boils and result in a steam that create bubbles that cause the perlite to expand more than its original size by 15-20 times [16]. Compared to normal perlite, the increase in volume leads to a significant reduction in bulk density, a reduction in the specific gravity and a significant increase in the water absorption. According to ASTM C330:2017 [17], expanded perlite aggregate is suitable in the production of lightweight concrete due to its low density.

(EPA) has a low bulk density compared to (NFA). As reported by Celik et al. [18], (EPA) has a density that range from 60 to 80 kg/m^3. According to Madadi et al. [19], utilization of (EPA) as a replacement of normal fine aggregate will significantly reduce the density and compressive strength. However, the greater the increase in the replacement level, the greater the reduction in density and strength. Oktay et al. [20] Replaced (NFA) with (EPA) by 10%,20%,30%.40% and 50%. The results showed a significant reduction in density and compressive strength that reached up to 50.17% and 91.26% respectively with 50% replacement. Also, Topçu and Işikdağ [21] reported by replacing 15%, 30%, 45%, 60%, 80% of (NFA) with (EPA) will cause a significant reduction in density and compressive strength that reached up to 67.25% and 88.67% respectively with 80% replacement.

Lightweight concrete produced by (POC) has the potential to be used as an environmentally structural concrete. However, (POC) coarse aggregate has a porous nature and high (ACV) which is the main reason for strength reduction. While (POC) fine aggregate has a small effect in the reduction of density. So, this study aims to enhance the strength of (POC) lightweight concrete by partially replacing (POC) coarse aggregate with (NCA). Next, introduce (EPA) by partially replacing it with (POC) fine aggregate to reduce the density but up to 20% replacement in order to not reduce the strength significantly. Among all pervious publications, there is no publication have done any combination between (POC) and (EPA) in the production of lightweight concrete.

2. Mix Design

The mix design was done by using Department of Environment (DOE) method to design the control mix of (NWC) with grade 40 MPa [22]. The other mix proportions were done by partial and full replacement of fine and coarse aggregate using the absolute volume method. As a result, eight mix proportions were prepared and mixed in three phases. The first phase consists two mixes; (NWC) with grade 40 MPa and a mix with 100% replacement of (POC) as fine and coarse aggregate. This phase is considered as the control for other mixes.

The reason for considering the second mix as control is to see what are the maximum strength and lowest density that full replacement of (POC) could achieve and decide how much is the partial replacement with (NCA) that could be applied. The second phase consists of three mixes;

- 100% replacement of (POC) as fine aggregate, 80% replacement of (POC) as coarse aggregate and 20% of (NCA).
- 100% replacement of (POC) as fine aggregate, 85% replacement of (POC) as coarse aggregate and 15% of (NCA).
- 100% replacement of (POC) as fine aggregate, 90% replacement of (POC) as coarse aggregate and 10% of (NCA).

After all the mixes from the second phase were tested, the third mix was decided to be used in the third phase. This was dependent on the strength to density ratio and this mix has the highest value. In the third phase, a partial replacement of fine (POC) aggregate with (EPA) in three different percentages 10%, 15% and 20% was decided to prepare three mixes. Table 1 summarizes all the mix proportions for all mixes done in this research.

Table 1. Mix proportions (kg/m^3).

Concrete Mix		*W*	*C*	*W/C*	POC		Normal		EPA
					Fine	Coarse	Sand	Granite	
1	**N.C**	250	500	0.5	0	0	960	640	0
	C.C100%[a]	250	500	0.5	805.26	462.95	0	0	0
2	**C.C90%[a]**	250	500	0.5	805.26	416.65	0	64	0
	C.C85%[a]	250	500	0.5	805.26	393.51	0	96	0
	C.C80%[a]	250	500	0.5	805.26	370.36	0	128	0
3	**C.C90%[a]. P10%[b]**	250	500	0.5	724.75	416.65	0	64	12.53
	C.C90%[a]. P15%[b]	250	500	0.5	684.49	416.65	0	64	18.8
	C.C90%[a]. P20%[b]	250	500	0.5	644.22	416.65	0	64	25.06

W: Water, C: Cement, W/C: Water Cement Ratio, N.C: Normal Concrete. C.C: Coarse Clinker.
a: percentage of POC coarse aggregate. b: percentage (EPA) fine aggregate.

3. Materials and Properties

In this section, all the materials and their properties are given in detail.

3.1. Water

Tap water was used in mixing and found acceptable for concreting.

3.2. Cement

Ordinary Portland cement CEM I 42.5 with a specific gravity of 3.15 was used in this experimental program which meets the specifications mentioned in BS EN 197-1:2000 [23].

3.3. Aggregate

(NCA), (NFA), (POC) fine and coarse aggregate and (EPA) were used. All the coarse aggregates lie within the range of 4.75 mm to 10 mm. (EPA) as in Fig. 1, the size lies mostly within the range of 2.36 mm to 5 mm as in Table 2. For the mix design requirement, a sieve analysis was done for (NFA) to determine the percentage for fine aggregate that pass through 600 μm. The percentage was 35.53%. [17, 22, 24]

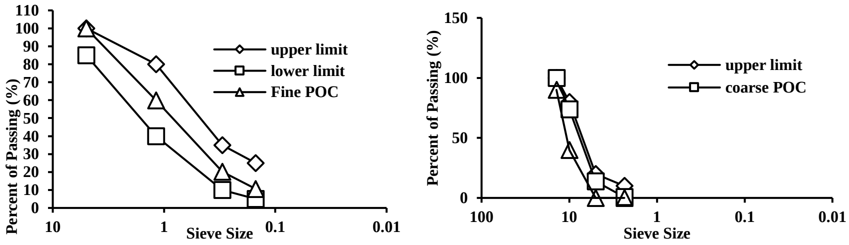
Fig. 1. Expanded perlite aggregate.

Table 2. Sieve analysis of EPA ASTM C330.

Sieve size (mm)	5	2.36	1.18	0.6	0.3	0.15	pan
Percent of Passing (%)	99.4	74.4	10.4	10.4	10.4	10	0

Also, the sieve analysis for the rest was done to make sure that the aggregates are well graded. Figure 2 shows the sieve analysis curves for fine and coarse (POC). According to ASTM C330:2017 [17], fine and coarse aggregates that resulted from using this waste material is classified as well graded because it lies within the upper and lower limit as stipulated in ASTM C330:2017 [17] and can be used as a replacement for (NWA) in structural applications.

The (POC) used in this study as shown in Fig. 3 was collected from a local Palm-Oil mill located in Johor, Malaysia. The raw material for clinker can be found within the size of 150 mm to 200 mm. Also, from Fig. 3(a) it is observed that the material is in an irregular shape, flaky and porous. Then it was crushed using the crushing machine and sieved to produce the required size of fine and coarse aggregate as shown in Figs. 3(b) and 3(c).



(a) Sieve analysis of coarse POC. **(b) Sieve analysis of fine POC.**

Fig. 2. Sieve analysis of POC aggregate [17].

(a) POC raw material. **(b) POC coarse aggregate.** **(c) POC fine aggregate.**

Fig. 3. Palm-oil clinker waste material.

Table 3 shows the specific gravity and water absorption for all types of aggregate used in this study.

Table 3. Properties of aggregates.

Aggregate	Normal Fine	Normal Coarse	POC Fine	POC Coarse	EPA
Specific Gravity	2.38	2.65	1.99	1.92	0.31
Water Absorption (%)	2.25	1.27	6.39	6.06	200

From the results shown in Table 3, both fine and coarse (POC) have a specific gravity less than 2. Based on this and according to ASTM C330:2017 [17], (POC) falls in the structural lightweight aggregate criteria. Furthermore, (POC) has water absorption higher than (NWA). Hossain [25] stated that lightweight aggregate has a water absorption higher than (NWA). As a result, in the early hydration age and as reported by Al-Khaiat and Haque [26], the poor curing effects on lightweight concrete with porous aggregate is minimal compared to (NWC). This is due to the additional water absorbed by lightweight aggregate and stored in its voids. Note that the water absorption of (POC) is considered as a benefit for hardened concrete.

4. Casting and Preparation of Specimens

(POC) and (NCA) were prepared by soaking it in water to be in saturated surface dry (SSD) condition. On the other hand, (POC) and normal fine aggregate were dried for 24hr in the oven and then extra water that was required to reach (SSD) condition was added to the mix. This extra water was determined by using the water absorption value for each type of fine aggregate which is according to BS 1881: Part 125:2013 [27]. All mixes were mixed in the same procedure according to BS 1881: Part 125:2013 [27]. The first half of coarse aggregates were added, then all fine aggregates were added, after that the remaining coarse aggregates were added. The mixer started to mix the aggregates for 30 s and while mixing half of the water was added. The mixing last for 3 min and then the mixer was turned off for about 15 min to make the fine aggregates absorb the required water to fill the voids. After that all the cement content was added to the mix and stared the mixer for 30 s.

Lastly, the remaining water was added and all the contents mixed for 3 min. This procedure was used to make sure that the mix is homogenous. After it was properly mixed, slump test was done for all mixes as recommended by BS EN 12350-2:2009 [28]. Steel cube moulds with 100 mm were prepared to cast the samples. The compaction was done in two stages. First, the moulds were filled in three layers and each layer was compacted by using a steel rod. Then the vibration table was used to ensure all the samples were compacted properly. After 24 hr, all the cube samples were demoulded. Then all the samples were cured in air-cure condition for 7 days and 28 days. Three cubes were prepared for each of 7 and 28 days.

5. Results

5.1. Slump and workability

The concrete consistency is measured by slump test [14]. This test is considered as the standard test for the concrete workability according to BS EN 12350-2 [28]. Table 4 shows the results of slump values for all mixes which lie within the range of 80 mm to 150 mm and it is satisfactory as long as it is in the designed slump range 60 mm to 180 mm. In the first and second Phase, it was observed that with more increasing of POC, the slump value got higher. The reason for that may due to the soaking of coarse aggregate 24 hr before casting and the extra water added to the mix required to make the fine aggregates in (SSD) condition. For the third Phase, in addition to those reasons, (EPA) has a high-water absorption compared to other types of lightweight aggregates, which may lead to more increase in the slump.

Table 4. Slump test values.

	Phase 1		Phase 2			Phase 3		
	N.C	C.C 100%	C.C 90%	C.C 85%	C.C 80%	C.C 90%. P10%	C.C 90%. P15%	C.C 90%. P20%
Slump (mm)	80	130	110	110	95	120	130	150

N.C: Normal Concrete, C.C: Coarse Clinker.

5.2. Density

The density for all mixes was measured after 7 and 28 days of air curing according to BS EN 12390-7:2013 [29]. The Table 5 summarizes the density of all mixes.

Table 5. Densities for 7 and 28 days.

Density Kg/m^3	Phase 1			Phase 2		Phase 3		
	N.C	C.C 100%	C.C 90%	C.C 85%	C.C 80%	C.C 90%. P10%	C.C 90%. P15%	C.C 90%. P20%
7 Days	2250	1888.33	1920	1956.67	1998.33	1905	1895	1884
28 Days	2245	1871.67	1900	1932.88	1970	1880	1866	1847

5.2.1. Phase (1) and phase (2)

Figure 4 shows the effect of substitution of (NCA) with (POC) coarse aggregate. With more increasing in replacement, the more reduction in density. C.C100% holds the highest reduction rate with 16.074% and 16.629% for 7 and 28 days, respectively. C.C90%, C.C85% and C.C80% hold a reduction rate of 15.367%, 13.902% and 12.249% for 28 days, respectively. This reduction in concrete density is due to the low bulk density of (POC) coarse aggregate with respect to (NCA). Nhaveen and Jeyakumar [30] stated that the use of crushed clay bricks by 100% instead of (NCA) reduced the hardened density by 13.4%. This reduction is because crushed clay bricks have a density lower than (NCA) by 45%. In accordance to BS EN 13055-1:2003 [31], all the mixes are considered as lightweight concrete class D2.0 (>1800, <2000) kg/m^3.

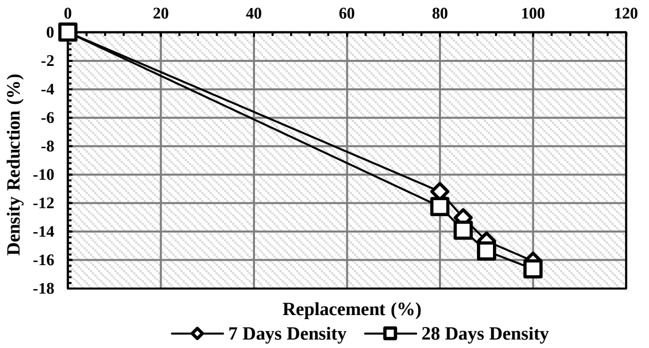


Fig. 4. Effects of coarse POC on density reduction.

5.2.2. Phase (3)

In this Phase, a partial replacement of fine (POC) with (EPA) 10%,15% and 20% is done to reduce the density because (EPA) has a lower bulk density than fine (POC). A small level of replacement was chosen in order to not affect the strength significantly. The mix C.C90% was chosen as a control mix for this Phase as will be explained in the next section.

In Phase 2, the attempt was to investigate the effect of (POC) coarse aggregate in the reduction of density and strength. (POC) coarse aggregate has a high rate of reduction in density, which reach to 16.629% at 28 days. But in return, the strength reduced by 39% due to the porous nature of (POC) coarse aggregate. Figure 5 shows the reduction rate of density with replacement level. The highest rate of reduction was for 20% replacement of (EPA) 1.875% and 2.789% for 7 days and 28 days hardened density, respectively, compared with mix C.C90%.

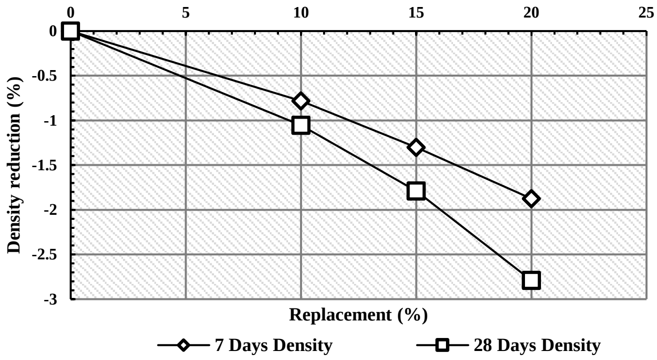


Fig. 5. Effects of EPA on density reduction.

5.3. Compressive strength

The compressive strength test was done according to BS EN 12390-3:2013 [32]. The strength results were determined by taking the average strength of three samples for 7 days and 28 days. Table 6 shows the results of the strength for all mixes in 7 and 28 days.

Table 6. Compressive strength (MPa).

Compressive Strength (MPa)	Phase 1		Phase 2			Phase 3		
	N.C	C.C 100%	C.C 90%	C.C 85%	C.C 80%	C.C 90%. P10%	C.C 90%. P15%	C.C 90%. P20%
7 Days	38.02	22.96	29.26	30.29	32.83	27.54	26.50	26.01
28 Days	45.41	27.70	35.49	35.56	36.74	34.32	33.65	33.20

5.3.1. Phase (1) and phase (2)

Figure 6 shows the results of compressive strength with different levels of replacement in Phase 1 and Phase 2 together for 7 and 28 days. From Fig. 6, it can be concluded that the maximum drop in strength occurred in mix C.C100% of full replacement of (POC) with a maximum strength of 22.96 MPa and 27.7 MPa in 7 and 28 days, respectively. This reduction in strength was caused by the porous nature of coarse (POC) aggregate. According to Abutaha et al. [14], (POC) coarse aggregates are irregular in shape and have a high number of voids, which lead to a reduction in the strength capacity of concrete.

Figure 7 shows the relationship between the level of replacement (%), 28 days hardened density and 28 days compressive strength for Phase 1 and Phase 2. Another factor that also explains the reduction in concrete strength is the aggregate crushing value (ACV) of (POC) coarse aggregate. As stated by Kanadasan and Razak [13], (POC) coarse aggregate could have a value of (ACV) higher than (NWA) by three times. This can be attributed to the (POC's) highly porous and honeycombed composition causing rapid load propagation to quickly collapse. The pores inside the (POC) internal structure cause a reduction in the mix density which lead to a reduction in the strength carrying capacity of the mix [14]. Mixes of Phase 1 and 2 gained more than 80% of their strength at the age of 7 days. The reduction rate in strength at the age of 28 days of all mixes with respect to N.C mix was 39%, 21.85%, 21.7 and 19.1%, respectively. As mentioned above, the reason for this high rate of reduction was due to the porous nature of (POC) coarse aggregate.

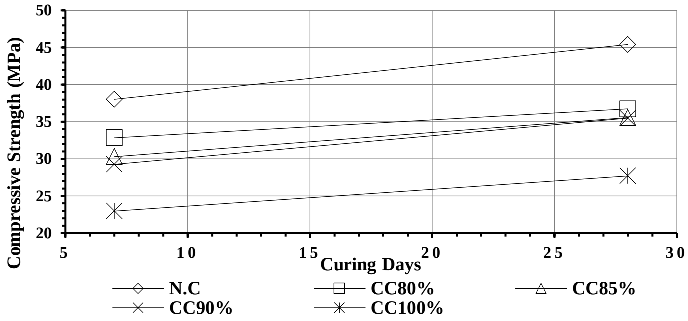


Fig. 6. Compressive strength at 7 and 28 days.

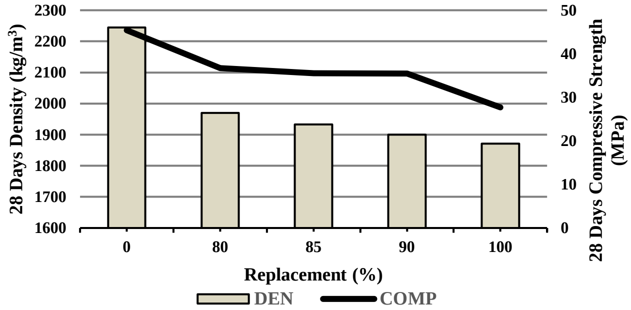


Fig. 7. Replacement, density and compressive strength relationship.

But in spite of that, the mix C.C100% with full replacement of (POC) coarse and fine aggregate can achieve 61% of the control (NWC) mix strength and can be considered as a structural lightweight concrete with 27.7 MPa strength. Figure 8 shows the relationship between the strength and density at the age of 7 and 28 days for Phase 2. This figure shows the linear relationship between the strength and density of concrete for different levels of replacement. With more increasing in the replacement of (NCA) with (POC) coarse aggregate, density and strength decrease. This is due to the high (ACV) and low density of (POC) coarse aggregate.

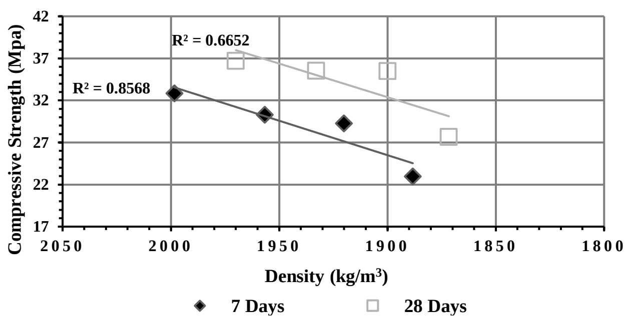


Fig. 8. Compressive strength and density relationship.

5.3.2. Phase (3)

From Fig. 6, it can be observed that mix C.C85% and mix C.C90% has almost the same 28 days strength with 35.56 MPa and 35.49 MPa, respectively. But for the density, C.C90% mix has a density of 1900 kg/m^3, which is 1.71% less than the density of C.C85% mix, which is 1932.88 kg/m^3. For these reasons, C.C90% mix was chosen for Phase 3. The aim of Phase 2 was to replace different percentages of (POC) coarse aggregate with (NCA) and decide which has the best result of strength to density ratio. Mix C.C90% has the best value of 1.868%. Figure 9 shows the compressive strength of Phase 3 mixes and C.C90% from Phase 2 as a control mix for 7 and 28 days. The maximum drop in strength was in mix C.C90%.P20% of 26.01 and 33.20 for 7 and 28 days, respectively. The reduction rate in the strength at the age of 28 days for all three mixes C.C90%.P10%, C.C90%.P15% and C.C90%.P20% compared with C.C90% was 3.3%, 5.18% and 6.45%, respectively. As compared to Phase 1 and 2 with coarse aggregate replacement, it can be concluded that the main reason for strength reduction is (POC) coarse aggregate.

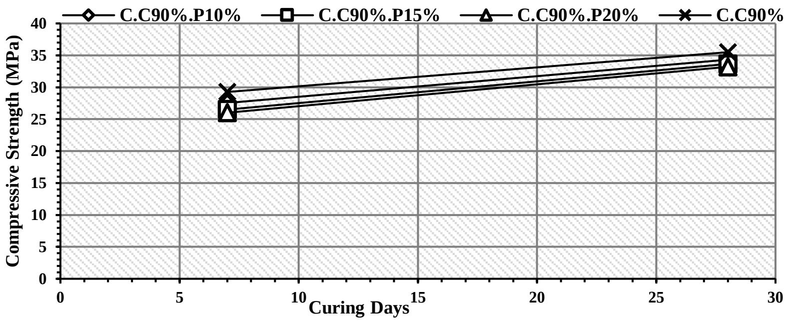


Fig. 9. Compressive strength at 7 and 28 days.

Figure 10 shows the relationship between the strength, density and level of replacement of (EPA) at the age of 28 days for Phase 3. This figure shows that with more increasing of replacement of POC fine aggregate with (EPA), the more reduction of strength and density. However, even with the reduction of the strength of all mixes, C.C90%.P20% with the lowest strength can be considered as a structural lightweight aggregate with a density of 1847 kg/m^3 and strength 33.20 MPa. Also, Fig. 11 shows a high correlation as the reduction in density has a linear relationship with replacement level.

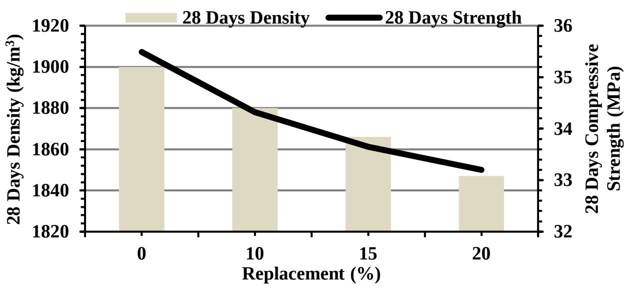


Fig. 10. Replacement, density and compressive strength relationship.

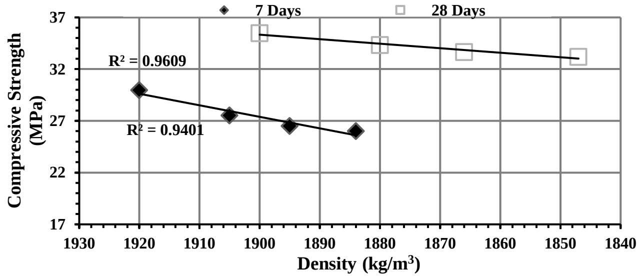


Fig. 11. Compressive strength and density relationship.

5.4. UPV

Significant information on the rate of pulse transfer in concrete samples has been provided by UPV results, which is linked indirectly to the concrete porosity. It is important to analyse the results of UPV because it provides the concrete denseness and especially due to the incorporation of (POC). Table 7 shows the results of UPV test for all mixes at 7 days and 28 days curing according to BS 1881:203 [33].

Table 7. UPV test results.

UPV (Km/s)	Phase 1		Phase 2			Phase 3		
	N.C	C.C 100%	C.C 90%	C.C 85%	C.C 80%	C.C 90%. P10%	C.C 90%. P15%	C.C 90%. P20%
7 Days	4.065	3.534	3.5842	3.597	3.610	3.5842	3.5778	3.5714
28 Days	4.098	3.555	3.623	3.663	3.676	3.610	3.606	3.605

According to BS 1881:203 [33], which classified that the quality of concrete depends on the UPV value, all the mixes lies within the range of good quality. Table 8 shows the classification of concrete depends on UPV values [33].

Table 8. Concrete quality classification.

UPV (km/s)	⩾ 4.5	3.5 – 4.5	3.0 – 3.5	2.0 – 3.0	⩽ 2.0
Classification of Concrete Quality	Excellent	Good	Medium	Doubtful	Very weak

5.4.1. Phase (1) and Phase (2)

Figure 12 shows the UPV values for each level of replacement of coarse aggregate. The propagation of the wave through samples is influenced by the porous and the irregular shape of (POC) aggregate nature. Also, the pulse velocity decreased due to the air obstructing effect in the empty voids between and inside the (POC) coarse aggregate. The mix C.C80% that has the highest percentage of (NCA) by 20%. This mix has the highest value of UPV compared to other replacement. This is because gravel has fewer voids, which make the concrete denser and make the pulse transfer faster across the samples.

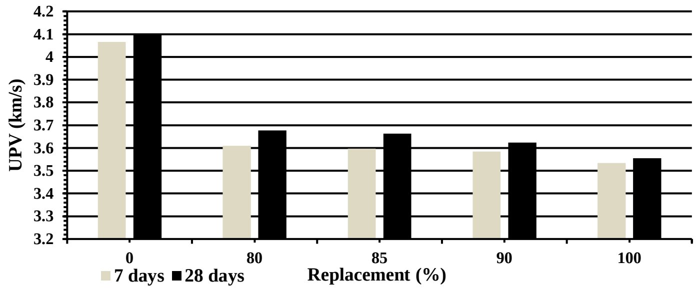


Fig. 12. UPV results with different levels of replacements coarse POC.

5.4.2. Phase (3)

Figure 13 shows the effect of (EPA) replacement on the UPV results. From the results, it can be observed that there is no significant reduction in the UPV values. It could be resulted because of the small size of (EPA) that have small size of voids. Apart from that, all the mixes within this Phase classified within the good quality.

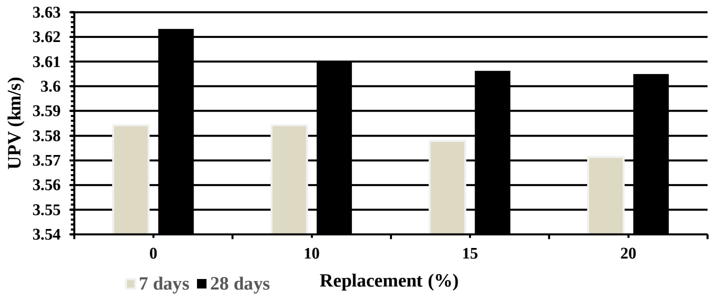


Fig. 13. UPV Results with Different Levels of Replacements EPA.

6. Conclusions

From this experimental work, some conclusions have been outlined and illustrated as follow:

- The waste material POC is produced in large quantities specially in Malaysia and some other countries and have properties that make it suitable to use as a replacement of natural aggregate in the production of concrete.
- Using the combination of POC and EPA in the production of lightweigth concrete is limited and no previous publication can be found on using both material in the production of lightweight concrete.
- POC has the potential to be used as an aggregate in the production of lightweight concrete. But due to the same property that all other lightweight aggregates have. POC coarse aggregate has a high ACV due to its porous nature.
- Redcution in density and increase in strength occurred when using 90% POC coarse aggregate, 10% of normal coarse aggregate, 80% of POC fine aggregate and 20% of EPA compared when using 100% POC coarse and fine aggregate.

- Using perlite as a replacement of fine POC with small percentages not more than 20%, lead to reduce the density and strength by 2.789% and 6.45%, respectively.
- All mixes in the third Phase reached a strength more than 30 MPa and a lightweight density. So, this new type of concrete classified as structural lightweight green concrete and can be useful in precast concrete production.
- For future work, its recommended to do tests in more than 28 days. Try to use different percentages of replacement. And test the bond between this new type of concrete and rebars.

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Abbreviations

ASTM	American Society for Testing and Materials
BS	British Standard
BS EN	British Standard European Norm
EPA	Expanded Perlite Aggregate
HWC	Heavy Weight Concrete
LWC	Lightweight Concrete
NCA	Normal Coarse Aggregate
NFA	Normal Fine Aggregate
NWA	Normal weight Aggregate
NWC	Normal Weight Concrete
POC	Palm-Oil Clinker
UPV	Ultrasonic Pulse Velocity

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