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Review Article

LIGHTWEIGHT CONCRETE USING LOCAL NATURAL LIGHTWEIGHT AGGREGATE

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Abstract
Volcanic materials such as pumice are used in the production of concrete as partial replacement of natural aggregates to produce lightweight aggregate concrete (LWAC). In the present study an attempt has been made to investigate engineering properties of a novel lightweight aggregate concrete (LWAC) utilising a locally available lightweight aggregate (LWA) called pumice aggregate (PA). This novel LWAC is made by partial replacement of coarse aggregate with different replacement levels of 10%, 20%, 30%, 40%, and 50% of PA by volume. This study is focused to determine the mechanical and durability properties of LWAC to find the optimum replacement level of PA. The properties of LWAC using different percentages of PA were reported by conducting comprehensive series of tests on workability, compressive strength, density, total water absorption and ultrasonic plus velocity (UPV). It is concluded that the LWAC has sufficient strength and adequate density. However, compared to normal concrete, the LWAC containing PA has lower strength and workability, and has more water absorption, but It is widely can be used in different applications of civil engineering including walls of pumice block which insulate both heat and sound and reduce the dead load of building. As a result of this study, LWAC having a minimum compressive strength of 6.98 MPa and a density of 1716 kg/m^3 were obtained.

Keywords: LWAC, Pumice, Strength, LWA and Density

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RESEARCH BACKGROUND

Lightweight concrete (LWC) is not a new material is back over three thousand years ago by Hindus that creating famous towns of Mohenjo daro and Harappa, also there are three famous LWC structures in the Mediterranean region: the port of Cosa, the Pantheon Dome, and the Coliseum, which were all built about two thousand years ago (Satish & Leif, 2002; Parhizkar, et al., 2012). The earliest invention and development of LWC was designed by using the locally available lightweight aggregates to the Romans which were made by using the Grecian and Italian pumice (Parhizkar, et al., 2012; Manguriu, et al., 2012).

In previous studies, many researchers have investigated the physical, mechanical and durability properties of lightweight aggregate concrete (LWAC) incorporating different types of lightweight aggregate (LWA), especially using pumice aggregate (PA) in different countries. Generally, the PA has more pores which has high water absorption (Hossain et al., 2011) and less density than normal weight aggregate (NA). Therefore, compressive strength, density of LWAC produced with pumice aggregate is expected to be less than the concrete produced with normal aggregate. For example based on an investigation conducted by Rajeswari & George, (2016), a reduction of 65% in compressive strength compared with normal concrete has been obtained with replacement levels of PA ranging from 50-65%. Therefore, the majority of studies have indicated that this type of LWAC can be utilized in wall panels of non-load bearing and in low-strength applications. The results also indicated that the LWAC reduced dead weight and improved thermal and sound insulation properties. Similar results have been reported elsewhere (Minapu, et al., (2014); Muralitharan and Ramasamy, (2015); Rao, et al., (2013); Zaetang et al., (2013).

According to the recent investigation (Bogas, et al., 2013) the LWCs with less porous aggregates have lower UPV compared with conventional concrete. The correlation between UPV and compressive strength was less affected by different types of binder and additions or by various initial wetting conditions of the aggregates. As predicted, the UPV and compressive strength of lightweight concrete affected by the water/binder ratio and the age. However, compressive strength less affected by W/C unlike UPV. The correlation between compressive strength and UPV of lightweight concrete and normal weight concrete was different depending on mix design parameters

The main aim of this experimental study is to produce a novel LWAC using a locally available natural LWA from mountains near Soran town, Kurdistan, Iraq without using any admixtures due to economic issues, which has a lower density, better physical properties and high thermal insulation. The specific objectives of the present study are assessing mechanical and durability properties of this novel concrete and identify correlation between these investigated properties.

EXPERIMENTAL METHODOLOGY

Materials

Cement

Portland Limestone Cement: CEM II/A-L 42.5 R (EN 197-1:2011) produced by Lafarge-Iraq cement manufactory, was used in all mixes throughout this investigation. The chemical, physical and mechanical properties of this cement are presented in Table 1.

Table 1: Typical Properties of cement-Karasta CEM II/A-L 42.5 R (Lafarge, 2017)

Parameters	Range
Lime Saturation Coefficient	0.96 - 1.04
Magnesium Oxide (MgO) %	1.5 - 2.5
SO3 Content %	2.2 - 2.6
Chloride Content %	0.01 - 0.03
Fineness (m^2/kg)	360 - 380
Initial Setting Time (min)	125 - 180
Final Setting Time (Hr)	3 - 3.7
Soundness Letchatelier (mm)	0 -2
Specific Gravity (kg/Litter)	3.05 - 3.15

Bulk Density (kg/m^3)		1.369 ± 0.1
Compressive Strength as per EN 197-1 (MPa)	2 days	22 - 27
	7 days	37 - 42
	28 days	46 - 52

Fine Aggregate

Locally available river sand of 4mm maximum size was used in this investigation. The fine aggregate grading size distribution is shown in Table 2 and Fig. 1. Results are according to Fine-Aggregate Grading Limits (ASTM C 33/AASHTO M 6).

Table 2: Requirements and grading of fine aggregate

Sieve Size		Accumulative % Passing	Accumulative % Passing
9.52 mm	(3/8 in.)	100.00	100
4.75 mm	(No. 4)	87.00	95 – 100
2.36 mm	(No. 8)	74.00	80 to 100
1.18 mm	(No. 16)	57.00	50 to 85
600 µm	(No. 30)	31.00	25 to 60
300 µm	(No. 50)	13.00	5 to 30 (AASHTO 10 to 30)
150 µm	(No. 100)	6.00	0 to 10 (AASHTO 2 to 10)
Fineness modulus = 3.32			

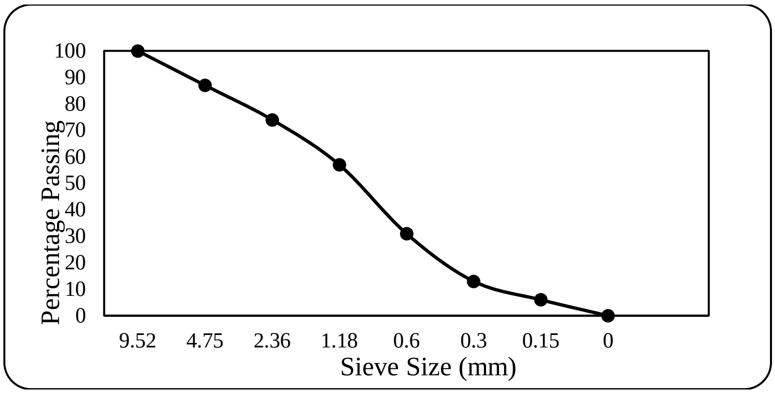

Fig. 1: Grading curve of fine aggregate

Coarse Aggregates

A) Normal Weight Coarse Aggregate

Natural coarse aggregate with 19mm maximum aggregate size was used in concrete mixes. The physical properties of coarse aggregate were tested in laboratory like specific gravity, bulk density, water absorption and fineness modulus according ASTM D-75 and ASTM C-136 and C-29, and the results are presented in Table 3.

Table 3: Physical properties of pumice and natural coarse aggregate

Property	PA	NCA
Bulk Specific Gravity(OD)	--	--
Apparent Specific Gravity	0.599	1.62
Absorption %	26.7	2.11
Dry Unit Weight (kg/m3)	599	1620
Fineness Modulus	6.86	6.27
Particle Shape/Texture	Porous/Rough	Sub angular/Partially rough
Colour	Wight	Dark Grey
Type	Uncrushed	Crushed
Maximum Size (mm)		

B) Pumice aggregate (PA)

Locally available pumice aggregate was used as partial replacement of natural coarse aggregate in the present work. Pumice was obtained from natural deposits in Soran, Kurdistan-Iraq. The properties of normal gravel aggregates are compared with those PA and summarized in Fig. 2 and Table 4. The bulk density results show that the PA is much lighter than normal aggregate. The oven dry density of PA is around 599 kg/m^3. As per ASTMC29/C29M, the dry loose bulk density of PA satisfies the requirement of lightweight coarse aggregate for structural concrete should less than 880 kg/m^3. However, the water absorption in PA is 26.7, higher than the range of 5% to 20% as normally occurred in other lightweight aggregates. High water absorption also indicates high degree of porosity in PA. The chemical composition of volcanic pumice is presented in Table 5.

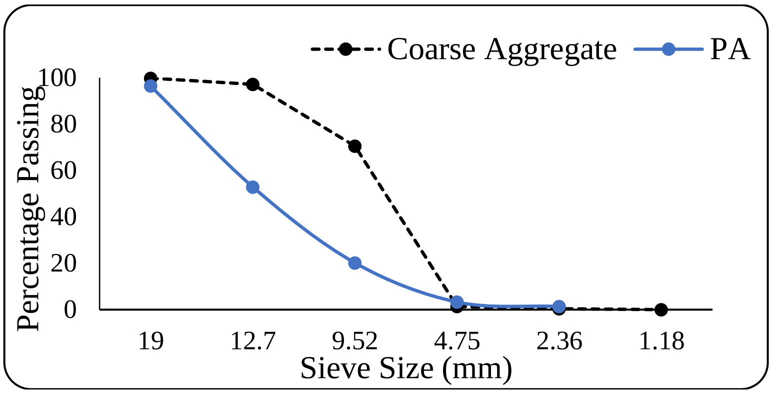

Figure 2: Grading curve of Coarse aggregate and pumice

Table 4: Grading of aggregates

Sieve opening	Coarse aggregate		
	Lightweight		Normal Weight
	PA	ASTM C-330	
25	100	100	100
19 mm	96	90-100	100
12.5 mm	53	-	97
9.5 mm	20	10-50	71
4.75 mm	3	0-15	1
2.36 mm	1		0

Table 1: Typical Chemical Composition of pumice stone (Pravallika & Rao, 2016)

Oxide composition	Volcanic Pumice %
SIO_2	71.91
AL_2O_3	12.66
Fe_2O_3	1.13
CaO	1.46
Mgo	0.32
Na_2O	3.45
K2O	4.3
Calcification lors	4.53
Specific Gravity	0.8

Water

Ordinary tab water was used in this investigation for mixing and curing all concrete samples and it's free from impurities that could adversely affect the process of hydration and, consequently, the properties of concrete.

Mix proportion

Concrete is basically consisting three main components that includes aggregate (coarse and fine), binder (cement) and water. The proportion of control mix was 1 (cement): 2 (fine aggregate): 4 (natural coarse aggregate). Mix proportion was conducted according to ACI 213R-03. Six different concrete mixes were used, the amount of all materials is calculated according to above standards, as shown in Table 6. The natural coarse aggregate was replaced by PA. The quantity of coarse aggregates was calculated by using the specific gravity of natural coarse aggregate and PA due to the low density of PA. The water to cement ratio (w/c) of 0.5 is equally used for all concrete mixes. The natural coarse aggregate was replaced with 0, 10, 20, 30, 40 and 50% (by volume) of pumice aggregate, amount of water, fine aggregate and cement was kept constant for all concrete mixes. To obtain a fair casting and facilitate demoulding, the moulds are thoroughly oiled before casting. Casting were put in three layers and compacted by hammer for 35times for each layer. The cubes were covered with sheets and kept for 24 h at room temperature. After 24 hours, they were demoulded with care so that no edges were broken and were placed in the curing tank at ambient temperature for curing until the test time of 7-day, 28-days and 90-days.

Table 6: Details of concrete ingredients

Mixes	Pumice %	Aggregates (g)		FA.	Cement	Water
		CA.	PA			
Control	0	3528	0	1764	8820	4410
M2	10	3175	3530	1764	8820	4410
M3	20	2823	7050	1764	8820	4410
M4	30	2470	1058	1764	8820	4410

M5	40	2117	1411	1764	8820	4410
M6	50	1764	1764	1764	8820	4410
CA: Coarse Aggregate, PA: Pumice Aggregate, FA: Fine Aggregate						

Test Procedure

2.3.1 Slump Measurement

The workability of fresh concrete mixes were measured immediately after mixing by using slump test with the help of 300mm standard size of slump cone, according to ASTM C 143. Each concrete mix was examined for the behaviour in slump, segregation and bleeding. The slump observed was recorded. No segregation or bleeding was observed in the mix.

Density

Three cubes of 150 x 150 x 150 mm concrete specimens were taken out for density test of each mixes according to ASTM C567 (Test Method for Determining Density of Structural Lightweight Concrete). The fresh and dry density of concrete specimens was calculated. The fresh density of concrete was measured from the freshly mixed concrete immediately after mixing in accordance with Test Method C138/C138M. The concrete samples were moulded for determine the dry density of concrete mixes after 24 hours the moulds were removed for record the mass of the dried specimens. The density is calculated by the formula in kg/m^3:

$$\rho = \frac{W}{V} \qquad \text{Eq. 1}$$

Where ρ is density, where W is weight and V is volume.

Setting time

The setting time of cement were measured according to ASTM C191-13. The aim of this test is to determine the initial setting time of fresh cement. In this test, initial and final setting time of fresh cements is measured by Vicat apparatus as shown in Fig 3. First the fresh mortar is placed in the metal mould which is located at the bottom of the Vicat apparatus. The height is 40mm of the metal mould. After that, the needle of the Vicat apparatus is lowered gently to contact with the surface of the mortar and the bleeding water is removed which is accumulated at the surface of the sample. The initial setting time is started after 155 minutes; the time is passed from the first contact with the mixing cement with water. The required condition of the initial setting time is started and repeated until the needle of the apparatus reaches the point 7mm from the bottom of the mould.

Fig. 3: Setting time test of cement

Compressive Strength

A set of three cubes of 150 x 150 x 150mm size were tested for each mixes of compressive strength at three different times of curing of 7, 28, and 90 days as per ASTM C39/C39M. Until the day of testing, the specimens were stored in the water tank at a temperature 22±2oC. After removing specimens from the water tank, the test was carried out in a standard compression machine of 2000KN capacity, the load applied at a rate of 0.5 MPa/s, three samples for each test. The test samples were placed on to the compression machine (Fig. 4). The averages of results are conducted in analysing process.

Fig. 4: Compression machine

Ultrasonic Pulse Velocity Test

The most available non-destructive test method which used for evaluating concrete properties is ultrasonic pulse velocity (UPV). UPV can be considering as the most useable method to obtain a total control of concrete structures. Velocities were measured by the direct transmission method. This test was carried out at 90 days of curing as per ASTM C597-09 using a portable ultrasonic non-destructive digital indicating tester on 150 x 150 x 150mm cube specimens as shown in Fig. 5. This test based on the propagation of a high frequency sound wave which travels through the concrete.

In this method an ultrasonic pulse is generated by a pulse generator and transmitted to the surface of concrete through the transmitter transducer. Three measurements were taken for each 28 days age specimen by switching the position of the transducers between the two opposite faces of the concrete cubes.

Fig. 5: Ultrasonic Plus Velocity Test

Total Water Absorption

The total percentage of water absorption of concrete mixes was determined according to ASTM C-20. Cubes of 150 x 150 x 150 mm size were used. Fresh concrete samples were cast into the mould and compacted for removing the air in concrete. Three concrete specimens were prepared for each concrete mixes. The specimens were removed from moulds after 24 hours of casting and placed in water (100 % moisture condition) at room temperature (22 ± 2^{o} C) during 28 days as shown in Fig. 6.

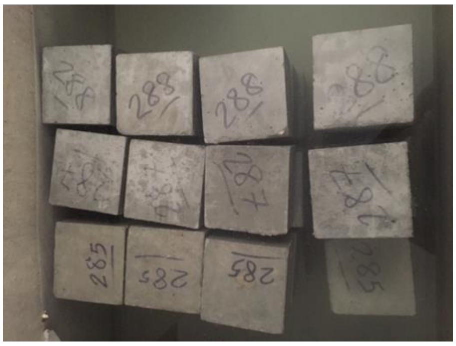

Fig. 6: water curing of concrete specimens

After 28 days curing period the samples were made oven-dry by placing them into oven (temperature 100°C) for 48 hours. Then the samples (oven-dry) were measured and recorded as an initial weight (oven-dry weight). After that, the samples were placed again into the water during 48 hours. Finally, samples were weighted after taken out from water to obtain the saturated weight of concrete samples. Total percentage of water absorption of concrete mixes was calculated by using following Equation.

$$WA(\%) = \frac{W2 - W1}{W1} \text{ X } 100 \qquad \text{Eq. 2}$$

Where:
WA (%) is Percentage of water absorption
W1 is Oven Dry Weight (initial)
W2 is Saturated Weight

RESULTS AND DISCUSSION

Workability

The workability (slump) values for concrete containing varying amounts of PA aggregate are presented in Fig. 7. Slump test measurements were carried out on all six mixtures. Slump test indicates the workability (consistence) of fresh concrete. The slump values are in the range of 0-165 mm.

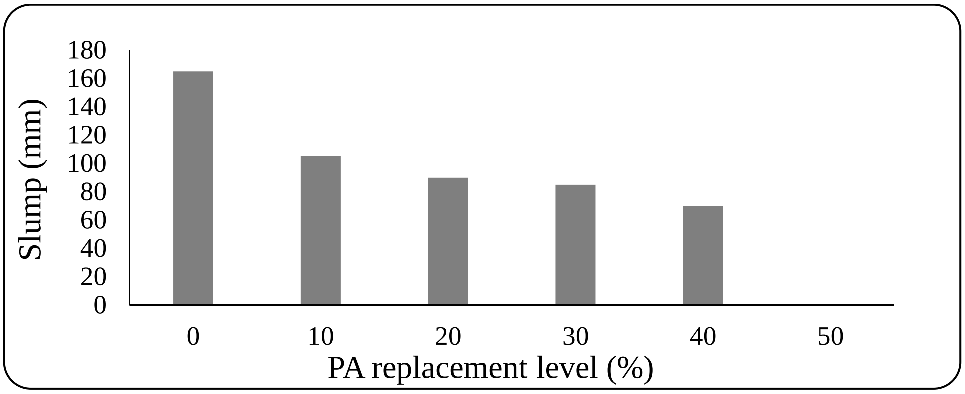

Fig. 7: Slump values of concrete

Slump values for normal concrete mix attains 165 mm, while unlike the study carried out by Muralitharan and Ramasamy, (2015), by increasing PA the workability of concrete decreased sharply. The decrease in the workability with higher percentage of PA is due to the high water absorption of pumice aggregate which has a higher porosity than the normal aggregate. With increasing the replacement level of PA from 0 to 10, 20, 30, 40 and 50%, the slump values for mixes with smaller w/c ratio of 0.5 are 165, 105, 90, 85, 70 and 0 mm, respectively.

Density

The fresh and dry density of concrete containing varying amounts of PA is presented in Fig. 8. The dry densities for concretes containing varying amounts of PA were in the range of 1717-2292 kg/m^3. The dry density of concretes decreased with the increase in PA replacement. Similar results have been reported by Rao, et al., (2013). The decrease in the fresh density was 2, 8, 14, 18 and 22% for concrete containing 10, 20, 30, 40 and 50% PA, respectively compared to control. The density and grading of aggregates, mix proportions, cement content, water/binder ratio, chemical and mineral admixture, method of compaction and curing conditions have a great effect on the density of concrete. The LWAC by using PA can be considered as lightweight concrete depending on PA replacement levels in concrete. Density of concrete is mainly controlled by the volume and density of aggregate and can control many physical properties in lightweight concrete.

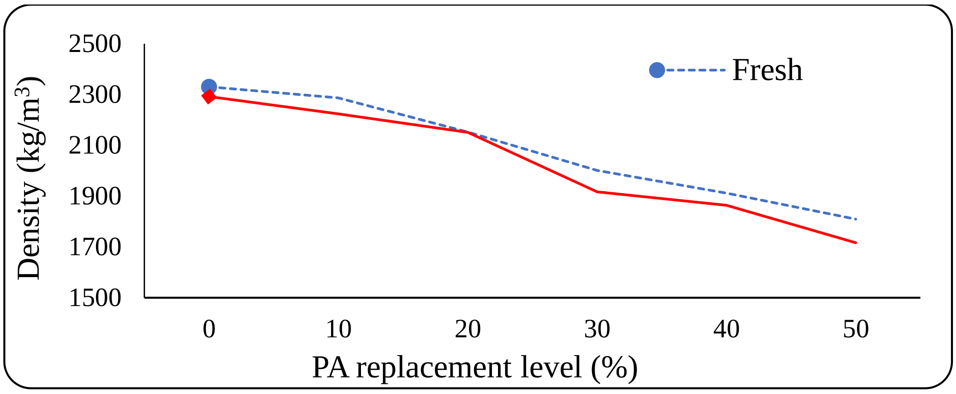

Fig. 8: Fresh and dry density of concrete

Compressive Strength

The compressive strength at the age of 7, 28, and 90 days of curing for concrete containing different amounts of pumice aggregate is presented in Fig. 9. The compressive strength values are in range of 7.0 – 25.6 MPa at 28-day age. Due to the lower strength of PA particles, the incorporation of PA caused a reduction in the compressive strength of concrete depending on the level of replacement with natural coarse aggregate. The compressive strength of the concrete at 28 days age decreased 1, 31, 55, 61 and 73% at PA content of 10, 20, 30, 40 and 50%, respectively, compare to the control of the same age Similar results have been reported by Minapu, et al., (2014). However, the 28-day strength for the concrete mix containing 20-40% PA in the present study is in the range of 12.58-17.12 MPa. According to BS 6073 part 1, the minimum strength required is 2.8 MPa for all blocks and 3.5 MPa for facing block. Strength requirements for building blocks are set at 2.5 MPa for filler blocks and 5.0 MPa for bearing blocks. A minimum strength of 7.5 MPa is required for special purpose and heavy duty bearing blocks. Therefore, for a target compressive strength of 7.5 MPa, all concrete mixtures with varying PA content (30, 40, and 50%) are suitable to produce all types of blocks including heavy duty bearing blocks (Minapu, et al., 2014). The concrete containing 10 and 20% PA can comply with the necessary minimum requirements of structural lightweight aggregate concrete (ACI and RILEM) which require a mean minimum strength of 17.0 and 15.0 MPa, respectively. Unlike control concrete (0% PA), the failure observed with concrete containing higher amounts of PA was more gradual and compressible under compressive loading, and the specimens were capable of retaining the load after failure without disintegration.

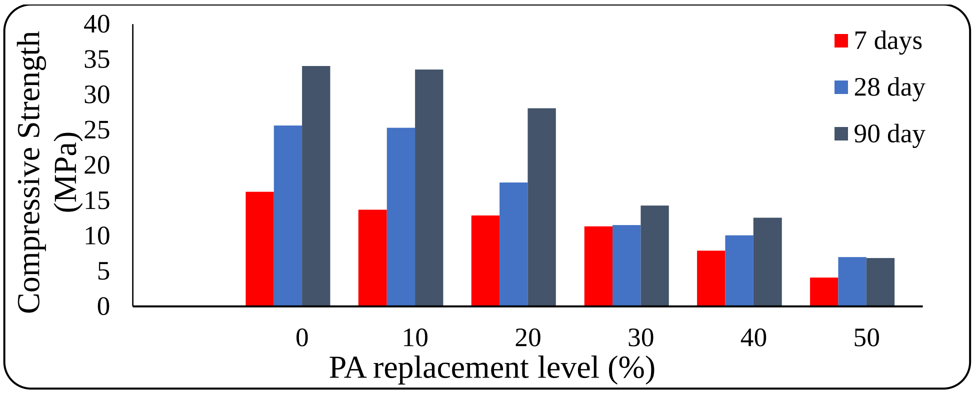

Fig. 9: Compressive strength of concrete at different ages

In the present study, the compressive strength increases with curing age for all mixes as expected. Control mix (0% PA) gained 63% of 28-day strength in the first 7 days of curing. This strength development for mixes 2 (10% PA), 3(20% PA), 4(30% PA), 5(40% PA) and 6(50% PA) are 98%, 82%, 42%, 37%, and 20%. The strength development for concrete mixes decreasing with increasing PA content in concrete.

Ultrasonic Pulse Velocity Test

The porosity of concrete materials indicates the speed of wave propagation, therefore the ultrasonic plus velocity (UPV) is depending on the density of concrete. Fig. 10 shows that with increasing the replacement level of pumice aggregate the UPV measurements proportionally decreased. The UPV value of conventional concrete was 3.84 Km/s, with increasing PA content by 10%, 20%, 30%, 40% and 50% the UPV was 3.3, 3.1, 2.6, 2.1 and 1.8 Km/s, respectively. Similar UPV values obtained by Bogas, et al., (2013).

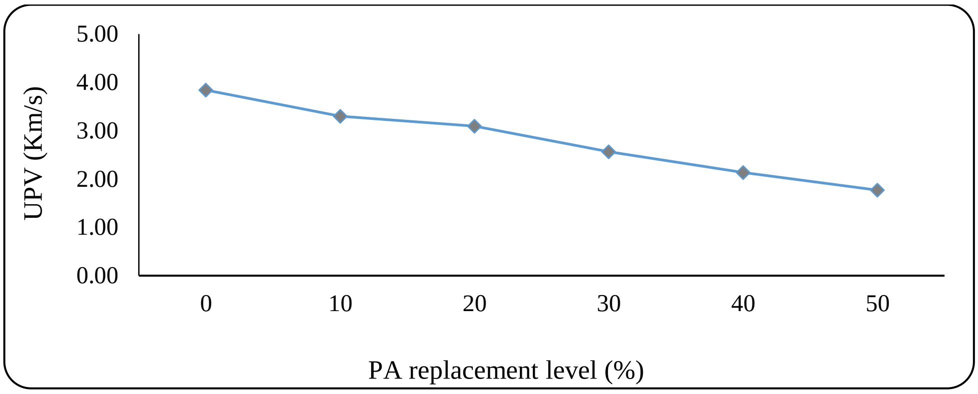

Fig. 10: UPV of concrete

Fig. 11 shows the correlation between compressive strength and UPV of concrete containing varying amounts of PA. An exponential function seems to better describe this correlation:

$$Y = 1.8836e^{0.8198x} \qquad R^2 = 0.9139$$

Eq. 3

The strength of concrete containing varying amounts of PA appears to increase with an increase in UPV of concrete (Bogas, et al., 2013). The equation is indicating the very strong correlation ($R^2 = 0.9139$), where X is the UPV (km/s) and Y is the compressive strength.

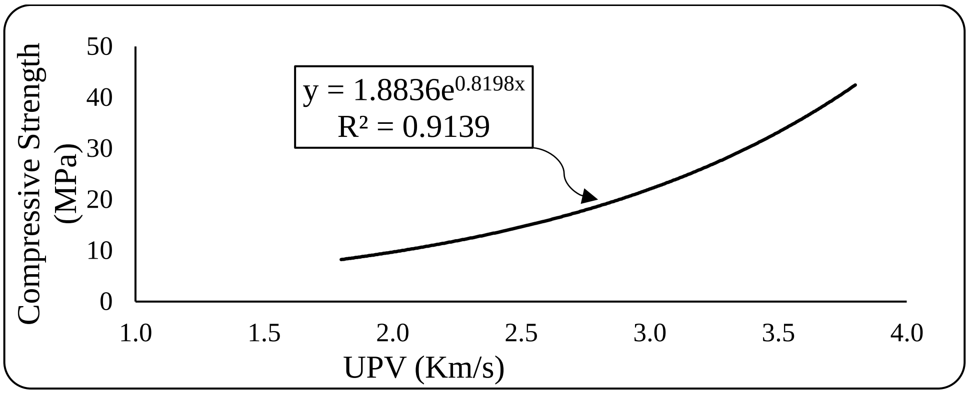

Fig. 11: Correlation between UPV and compressive strength

Total Water Absorption

The total water absorption of concrete containing different amounts of PA is presented in Fig. 12. At the 28-day age, the total water absorption of concretes is between 5.68-14.25%. It is obvious that water absorption increases with increasing pumice aggregate in concrete mixes. Similar results have been reported by Parhizkar, et al., (2012), water absorption was between 7% to 11%. The possibility of higher water absorption may be due to increasing porosity in concrete and decreasing durability of concrete and the shrinkage of particles similar results have been reported by Zulkarnain, et. al (2015). The results confirmed that an increase of about 14.25% in total surface water absorption found for a PA mix containing 50% compared to conventional concrete mix. Testing programs cleared that samples had high quality of lightweight concrete when they absorbed very little water and this showed their low density and permeability of LWC was extremely low and generally equal to conventional concrete. The absorption of lightweight aggregate ranges between 5 to 20 percent by mass of dry aggregate, after 24 hour of absorption and for use in structural concrete for good quality aggregate, it's not more than 15 percent is used (ACI Committee 213).

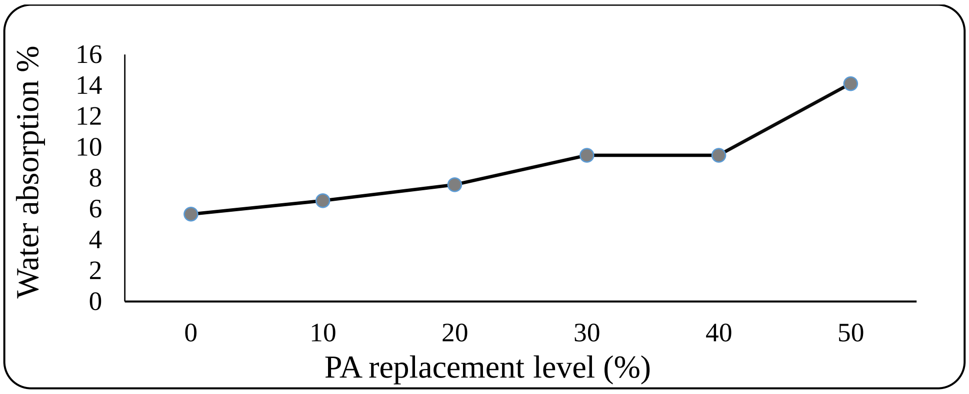

Fig. 12: Total water absorption of concrete

CONCLUSION

The main aim of this investigation was to evaluate the effect of a locally available lightweight aggregate called pumice aggregate (PA) on different engineering properties of concrete. The following conclusions can be taken from this research work:

1- By increasing PA the workability of LWAC decreased, density decreased and water absorption increased;
2- The higher reduction in compressive strength was in the concrete with higher replacement level of PA;
3- The compressive strength was increased with increasing curing age;
4- With increasing PA content UPV is decreasing proportionally;
5- There is a strong relationship between UPV and compressive strength with R^2=0.91 as UPV increases strength increases.
6- The concrete containing low PA can comply with the structural applications requirements and concretes containing high contents of PA can be used in different applications of the construction industry e.g. to produce lightweight concrete blocks and bricks with low thermal conductivity.

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