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EXPERIMENTAL INVESTIGATION ON MECHANICAL PROPERTIES OF LIGHTWEIGHT AGGREGATE CONCRETE

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Abstract

This present research work mainly focusses on an investigation of the workability and strength properties of lightweight aggregates, particularly Palm oil shell and pumice aggregate, used in the production of concrete with (PA) and (POS), which were substituted for conventional Hard Broken Stone (HBG) coarse aggregate. Through the use of lightweight aggregate (POS and PA) in place of some of the coarse aggregate, the properties of a lightweight concrete M30 have been concentrated in this experimental study. The lab tests that were conducted include the compaction factor test, Schmidt Hammer test (rebound hammer test), and compressive strength. A total of 108 numbers of cube specimen were employed of size 2400 kg/m^3. As part of a parametric study, the total number of cube specimens was divided into two groups according to various percentages: palm oil shell and pumice aggregate. In order to cast the cube specimens, dry weight of coarse aggregate was substituted for 0, 10 %, 20 %, 30 %, 40 %, and 50 % of POS and PA lightweight aggregate, respectively. A total of 9 cube specimens were cast and tested for 3, 7, and 28 days after successful curing in order to obtain accurate results. Average values were obtained from the test program and are shown in the corresponding Tables. Slump, compaction factor, rebound hammer compressive strength, and compressive strength values with different amounts of light aggregate were used to assess how well concrete performed when coarse aggregate was partially replaced with light aggregate. The test findings revealed that when the amount of conventional aggregates substituted by POS and PA increased, the slump test, compaction factor test, and strength of the lightweight aggregate concrete (LWAC) rapidly diminished. With an increase in the amount of aggregates replaced by POS and PA, the LWAC's absorption has gradually increased as water. It is stated at the outset that the POS has shown to perform better than the PA when construction is done using structural lightweight concrete.

Keywords:

Slump test;
Compaction factor test;
Schmidt hammer test;
Palm oil shell;
Pumice aggregate.

1 Introduction

Natural resources including water, sand, gravel, and crushed rock, which are currently in increasingly scarce, are mostly consumed by the concrete industry [1]. Concrete has significant compression and resistance characteristics. The use of normal weight aggregates, such as gravel and granite, has resulted in a decrease in natural rock deposits, and their continued exploration could cause environmental harm and ecological imbalance. It is therefore absolutely essential to find a suitable replacement material for the coarse aggregates used in the production of concrete [2]. According to [3] between 70 and 80 percent of the entire volume of concrete is made up of aggregate. Given how extensively aggregates are utilized in concrete, it is assumed that their influence on the material's characteristics and functionality will be substantial. Aggregates are required to transform

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concrete into an engineering material. They frequently have an effect on reducing moisture associated with deformation such as shrinkage of concrete and tend to provide volumetric stability to concrete.

Concrete, like stone, is an artificial substance used for a variety of structural purposes. Normal Weight Concrete (NWC) has a density of 2400 kg/m^3. Concrete with a mass per unit area of 500 to 2000 kg is known as LWC concrete. LWC could refer to concrete made from pumice aggregate and palm oil shell. LWAC, on the other hand, was produced from naturally existing aggregates of volcanic origin, such as pumice (shown in Fig. 1 and 2), and agricultural waste, such as palm oil shell. Different types of LWAC are used depending on how the mortar mixture is created. The raw materials used to make them, as well as the methods used to make them, have a significant impact on the properties of aggregates. LWAC use is increasing on a daily basis, and numerous studies and expansions are being conducted around the world to improve LWAC performance [4]. This research will focus on extremely important attributes such as workability, strength, and LWAC performance. Below is a quick description of LWAC materials' current strength characteristics based on the research that are available at the moment.

Natural lightweight aggregates, according to Bryan, Dennis S. P. [3] are essentially natural mineral materials with a low bulk density. Weight reduction is the primary control in the construction industry because it results in cost savings. Because of their lighter weight and inclusion of lightweight concrete masonry units and Portland cement concrete, NLWA products are used. Additionally, some NLWA use regular weight construction aggregates as typical backfill material and road base, depending on the locality.

On the mix design of the LWC with POS aggregates, Mannan and Ganapathy [4] monitored a test. The processes for mix design for POS concrete were found to be very different from those for conventional concrete containing crushed stone aggregates. The concept that the mix design is predicated on the aggregate properties was also revealed.

According to Owens, P. L. [5], the LWC has been used for structural purposes for a very long time. His research indicates that the LWAC has a low bulk density and is frequently composed of aggregates in a sphere-like shape. When compared to NWAC, which has a density of about 2400 kg/m^3, structural LWAC has a density that ranges from 1400 kg/m^3 to 2000 kg/m^3.

Hossain [6] took into account the POS aggregate's porous nature, low bulk density, and high water absorption. Hardened concrete was discovered to be lighter than traditional granite concrete due to the benefit of low bulk density. As a result, there is a significant reduction in the structure's overall dead load, which lowers the overall construction cost. In nations where earthquakes are unavoidable, the lightweight nature of the resultant concrete is essential because structures influence damaging inertia forces to lessen forces since these forces are eventually proportionate to the weight of the structure. When compared to palm oil shell, pumice aggregates absorb water at a rate that is roughly 37 % greater.

In comparison to conventional aggregate, most LWA generally have higher water absorption values. Lightweight concrete with lightweight aggregate has not yet been the subject of numerous experiments. However, normal weight concrete and artificial lightweight aggregate concrete (ALWAC) have received a lot of attention in research. The research of high-strength lightweight aggregate concrete benefits from having a basic understanding of the distinction between LWAC and NWC. The classifications, definitions, and restrictions of lightweight aggregate concrete are discussed in this section, along with the similarities between LWAC and NWC and research on the properties of aggregates produced from palm oil shell and pumice.

Germany was in control of a difficult exchange of light structural components around the world earlier in World War II [4]. Pumice was used in the construction of structures by the Greek and Roman civilizations. Isidore of Milctus and Anthemius of Tralles were two specialists sent by Emperor Justinian to work on Istanbul, Turkey's St. Sofia Cathedral or Hagia Sofia in the fourth century A.D. The Pantheon, a Roman temple, was constructed between 118 and 128 A.D. Between 70 and 82 AD, the eminent Pont du Gard aqueduct was constructed. The Romans used regular LWA and empty vases for their "Opus Caementitium" in addition to building construction to lighten the load. Additionally, this was employed in the Mayan era in Mexico during the construction of the Pyramids.

An office building with three stories that was built in 1958 close to Bent Portage in London served as the first fortified lightweight concrete structure in Great Britain. Since then, several structures have been constructed using precast, in-situ prestressed, or reinforced LWA. The LWAC's ship work near the conclusion of World War I in 1917 was another innovative deployment. Selma was the name of one of the illustrious ships. It is still in good shape even after so many years of use in a bad environment. These motivate the strength of the LWAC. Pumice is still used today in various

countries, including Turkey, Germany, Italy, Iceland, and Japan, to make lightweight, basic concrete and bricks. A few nations, including Malaysia, create LWA using POS. Its extensive use is due to its flexibility, as well as a number of other properties such as light weight, durability, and low manufacturing costs. The high use of plastics has resulted in an increase in solid waste, with domestic waste accounting for a significant portion of it [7]. In spite of their importance, however, aggregates tend very much to play 'second fiddle' to the other principal ingredient of modern concrete, namely portland cement [8]. Despite the increasing use and demand for lightweight aggregate concrete (LWAC), there is still a lack of adequate explanations to understand the mechanisms responsible for the strength and durability properties of LWAC. This book is written to give an overall picture of LWAC, from the historical background, aggregate production, proportioning and production of concrete, to applications in structures. Physical properties and chemical durability are described in detail. The physical properties include density, strength, shrinkage, and elasticity. Chemical durability includes resistance to acids, chloride ingress, carbonation, and freeze-thaw resistance. Fire resistance is also included, which is seldom considered, but is a very important aspect of the safety of the structure [9]. Natural lightweight aggregates (NLWA) may be defined as inherently low density and natural mineral materials. In construction trade, the main control is on weight reduction because it equates to cost savings. NLWA products are used because of its lower density which contain lightweight Portland cement concrete and lightweight concrete masonry units. In addition to this based on location also some of the natural lightweight aggregates are taking part with normal weight constructions aggregates for uses like road base and common backfill material [10]. The density of structural LWAC is ranges from 1400 kg/m^3 to 2000 kg/m^3 compared with that of NWAC about 2400 kg/m^3 [11]. The low bulk density is advantageous, as the resulting hardened concrete was found to be lighter compared to the conventional granite concrete. This reduces the overall dead load on the structure, which comes with a significant amount of savings on the total construction cost. In addition, the lightweight nature of the resulting concrete plays a crucial role in countries where the occurrence of an earthquake is inevitable, as the catastrophic inertia forces that influence the structures can also be ultimately reduced, as these forces are proportional to the weight of the structure. In general, most lightweight aggregates have higher water absorption values compared to that of the conventional aggregate. Although, POS has a high-water absorption value, even higher water absorption values were recorded for pumice aggregates, which have a value of about 37 % [12]. Determined that the procedures for mix design of POS concrete differ broadly from those of the normal concrete, with crushed stone [16]. The clinker is incorporated into the concrete as a direct replacement for both fine and coarse aggregates at 100 % replacement level. The use of clinker lightweight concrete was found to save the amount of the total dead load up to 18.8 % [17]. The compressive strength of lightweight concrete by combination with 10 % OPS and 90 % coarse aggregate is found to be similar with the normal lightweight concrete from 100 % coarse aggregate. And with the increasing amounts of aggregates replaced by OPS, water absorption of the lightweight concrete has increased gradually. It is concluded that OPS concrete has sufficient strength to be accepted as structural lightweight concrete and that the trend of behaviour of OPS concrete and control concrete is very similar [18]. The deflections at different stages including service load and peak load stage were higher for GPC beams. However, the ductility factor was comparable to that of OPCC beams [19].

The construction industry is growing daily because of the expanding human population and current technology. Raw materials are used more frequently when making concrete. The weight of a structure is increased when granite or gravel are used in concrete construction. Therefore, a different approach to lowering structure weight is required. These problems can be resolved using lightweight concrete in the construction sector. In most cases, lightweight concrete does not use granite or gravel, but it still produces light structures. However, in order to use this concrete, some issues must be resolved. The mixing ratio is crucial for creating LWC mixtures of high quality. Care must be taken during the mixing process, particularly with LWC that uses chemicals, to ensure that the finished concrete meets the desired quality standards. This made it necessary for skilled workers to manage the process. It is possible to draw the generalization that concrete reinforced with crushed POS and pumice as CA can be used to reduce the self-weight of members, hence lowering the cost of heavier beam and column requirements, the quantity of reinforcing bar needed, and the foundation's bearing capacity.

2 Experimental program

The compressive strength and workability of LWAC are the main topics of this study. Separately developed mix designs for concrete with various proportions of POS and pumice aggregates. The slump test and the compaction factor test were used to assess the effectiveness of the mix designs. The lightweight aggregate concrete samples are prepared, and they underwent specific underwater cure times of 3, 7, and 28 days. A compression test and comparisons with traditional weighted concrete were done to ascertain the strength of the lightweight aggregate concrete [13].

Using the IS:10262-2009 [14] method and common concrete constituents, mix design for M30 concrete has been completed. The NWC has been replaced in the order of the current study in equal portions of the following five percentages: 10 %, 20 %, 30 %, 40 %, and 50 %. In order to investigate the characteristics of concrete, various specimens have been cast and tested. The research is conducted using a 0.45 water cement ratio.

The initial stage of the investigation has been planned out in a number of phases:

• **Step 1:** Fine aggregate, coarse aggregate (granite), water, cement, and LWA (pumice and palm oil shell), and cement are the main components of concrete. These ingredients have been obtained from various sources.

• **Step 2:** Based on the mix proportions, materials testing for lightweight concrete must be done.

• **Step 3:** The tests to be examined in this phase include the compressive strength test, Schmidt hammer test, compaction factor test, and slump test.

Below is a discussion of each material's specific requirements for this study:

2.1 Cement

After a number of experiments were completed using locally available Zuari Cement (OPC) of 43 grade of Cement Brand in compliance with IS 8112-1989, it was discovered that

- cement's specific gravity is 3.10,
- its standard consistency in percent is 34,
- initial and final setting times, respectively, are 43 and 128 minutes.

2.2 Fine aggregate

The locally accessible natural sand is obtained, and it is discovered that it complies with IS 383-1970's grading zone-III. According to the steps outlined in IS 383 (1970), numerous tests have been conducted, and it has been determined from them that.

The fine aggregate has a Specific Gravity of 2.60.

2.3 Coarse aggregate

Crushed stone aggregate has been manufactured in the laboratory that complies with IS 383-1970 and includes 10 mm and 20 mm size aggregate. It has undergone testing for a number of qualities, including

- specific gravity = 2.24,
- fineness modulus = 6.7,
- bulk density = 1800 kg/m^3,
- water absorption = 0.71 %.

2.4 Light weight aggregate

In this section lightweight aggregate such as POS and PA details have been discussed.

2.4.1 Pumice

Pumice is a naturally occurring, abundant resource that is safe for the environment. Pumice is currently used in lightweight concrete, but not to its full potential. Concrete constructions are frequently designed using the concrete's compressive strength. Mumbai is the source of the lightweight aggregate (pumice), as depicted in Fig. 1.

1) Lightweight aggregate sizes are 10 mm and 20 mm.
2) Pumice's Specific Gravity is 1.06.
3) Water absorption, in percent, is 46.23.
4) The bulk density is 574.5 kg/m^3.



Fig. 1: Pumice aggregate (currently in use).

2.4.2 Palm oil shell

The coarse aggregate was changed out for POS. They were gathered at the Godrej Agro Vet Ltd., A. P. - owned palm oil factory, which is seen in Fig. 2.

- The bulk density of palm oil shell is 590 kg/m^3.
- Its specific gravity is 1.15.
- Water absorption as a percentage is 33.30.



Fig. 2: Palm oil shell (currently in use).

2.5 Water reducers (SP)

Super plasticizers (Conplast SP430) were used to enhance flexibility to the freshly mixed LWA concrete. A high range water-reducing concrete additive is Conplast SP430. It is a highly effective liquid super plasticizer with dual actions that can either produce free-flowing concrete or to improve early and ultimate strength, concrete's water content should be greatly reduced.

2.6 Concrete mix design

The mixture's composition is, also known as mix design. Mix design is a procedure that enables engineers to choose the proper concrete constituents and In order to produce concrete with particular minimum properties, most notably consistence and strength, as inexpensively as feasible, determine their relative amounts. Prior to being air dried in the laboratory, they were soaked in water for 24 hours. For each type of concrete mix proportion, eight samples were made, and they were examined when they were 3, 7, and 28 days old. 56 cubes in total were created as a result for the tests. The uncrushed aggregate 20 mm and regular Portland Type I were both used in this study. In Tables 1 and 2, the mix proportions for LWA are displayed. The mix ratios for (M30 Grade) for POS are presented in Table 1. The mix ratios for (M30 Grade) for pumice are presented in Table 2. The slump test for various pumice percentages is presented in Table 3. The slump test for various POS percentages is presented in Table 4.

Table 1: Mix ratios for (M30 Grade) for POS.

Mix No.	Quantities in [kg/m^3]				
	POS	OPC	Water	F.A.	C.A.
M1 (0 %)	0.00	395	197	650	1185.0
M2 (10 %)	118.5	395	197	650	1066.5
M3 (20 %)	237.0	395	197	650	948.0
M4 (30 %)	355.5	395	197	650	829.5
M5 (40 %)	474.0	395	197	650	711.0
M6 (50 %)	592.5	395	197	650	592.5

Table 2: Mix ratios for (M30 Grade) for pumice.

Mix No.	Quantities in [kg/m^3]				
	POS	OPC	Water	F.A.	C.A.
M1 (0 %)	0.00	395	197	650	1185.00
M2 (10 %)	123.76	395	197	650	1113.84
M3 (20 %)	185.64	395	197	650	1051.96
M4 (30 %)	247.52	395	197	650	990.08
M5 (40 %)	309.40	395	197	650	928.20
M6 (50 %)	371.28	395	197	650	866.32

Table 3: Slump test for various pumice percentages.

Pumice aggregate (PA)	Coarse aggregate	Slump [mm]		
		1	2	Average
0 %	100 %	160	165	162.5
10 %	90 %	162	158	160.0
15 %	85 %	157	152	154.5
20 %	80 %	149	148	148.5
25 %	75 %	112	110	111
30 %	70 %	91	92	91.5

Table 4: Slump test for various POS percentages.

Palm oil shells (POS)	Coarse aggregate	Slump [mm]		
		1	2	Average
0 %	100 %	160	165	162.5
10 %	90 %	161	160	160.5
20 %	80 %	168	170	169.0
30 %	70 %	145	145	145.0
40 %	60 %	90	92	91.0
50 %	50 %	78	80	79.0

2.7 Concrete mixing

While going to the concrete mixing, the amounts of all components must be ready with the help of weighing scale machine. The steps in concrete mixing are as follows:

- Firstly, the coarse aggregates must be dumped into the tray, after that the FA and cement as well.
- Secondly, the mixture of FA's, CA's and cement were mixed systematically to attain the uniformity for around 5 min.
- Thirdly, water was poured gradually to the mixture.
- Finally, in order to get a uniform mixture, the mixture was stirred for about 10 minutes.

In LWA (Pumice and POS) pumice aggregate mixing is more difficult than mixing standard concrete. Pumice aggregate must be equally pre-wetted to the point of saturation then let to settle and allow the excess water to drain. Pumice mixed with water can be used to fill internal gaps left by the pre-wetting process, which reduces shrinkage cracks and prevents aggregates from drying out on the job site. Always avoid overvibrating or overfinishing concrete with pumice. When using NWC, the paste rises to the top due to segregation and over finishing. In pumice concrete coarser pumice particles float at the top, as depicted in Fig. 3. Similar to how regular concrete cures Compared to regular concrete, the removal of pumice concrete needs to wait an extra 24 hours [15].



Fig. 3: Pumice aggregate mixing process.

After the mixing procedure, some quantity of fresh concrete was utilized for testing the workability. The other concrete was poured into the formworks and utilized for the preparation of specimens.

2.8 Placing fresh concrete

The new-made concrete was dumped immediately into the form-work after regulating the workability test. The distant of pouring of concrete should be as little as far as feasible to prevent the separation. For the concrete cubes and beams, the movement were carried out with the help of vibrant table and hand compaction. The surface of the concrete was flattened to give a flat layer as shown in Fig. 4.



Fig. 4: Finishing surface of concrete cubes.

3 Results and discussion

The findings and discussion have been given in this section.

3.1 Slump test

A measurement for consistency is slump. The slump is the distinction between a 300 mm (12 inches) concrete cone that has been blunted and a slump that occurs from removing the moulding cone. Tables 3 and 4 show that the slumps for the POS and pumice concretes, respectively, varied from 79.0 mm to 162.5 mm and 91.5 mm to 162.5 mm. Because the 10 to 30 percent slumps occur between 145.0 mm and 160.5 mm for POS and 148.5 mm and 160 mm for pumice, they may be

categorised as having excellent workability. The 40 % combination can be described as having medium workability. As more coarse aggregate replaces POS and pumice aggregate, slumps become less severe, as seen by the findings, as shown in Fig. 3 of slump heights with various percentages of LWA. The slump is the distance between a 12-inches (300 mm) truncated cone of concrete and the slump down when the moulding cone is removed which was shown in Fig. 4. The slump heights for various LWA percentages are shown in Fig. 5.



Fig. 4: Slump test.



Fig. 5: Slump heights for various LWA percentages.

3.2 Compaction factor test

The POS and pumice aggregate concrete's respective compaction factors were 0.83 to 0.80 and 0.88 to 0.81. For concrete that falls into the standard range, the compaction factor ranges from 0.8 to 0.92. The slump test is inaccurate for dry mixes, which is where this test performs best. For workability of the normal sort, the sensitivity of the compaction factor is reduced outside of the concrete, and it is often insufficient for compacting values larger than 0.92. The slump test is now frequently used in place of this test to control the workability of concrete. According to Fig. 4, the test result, which varied from 0.83 to 0.80, can be explained as having medium workability. The compaction factor for various LWA percentages is shown in Fig. 6.



Fig. 6: Compaction factor for various LWA percentages.

3.3 Schmidt hammer test

The strength of hardened concrete in buildings is typically tested using the Schmidt hammer, also referred to as the rebound hammer. Figs. 8 and 9 illustrate the results of the Rebound Hammer Test on LWA (POS and pumice) concrete specimens, which show an increase in specimen strength with time. Compaction factor for various LWA percentages. The discrepancy between the compressive strength test and rebound hammer test results could be attributable to the unevenness of the concrete surface brought on by the inclusion of LWA (POS and pumice) in the specimens, which affects the concrete surface area. The strength test was conducted at various points, so the rebound number is not very precise. Depending on the strength of the aggregate that the rebound hammer may strike, a higher rebound number. Testing quality of hardened concrete with rebound hammer is shown in Fig. 7. The strengths of the POS's rebound hammers on various curing days are shown in Fig. 8. The strengths of the Pumice's rebound hammers on various curing days are shown in Fig. 9.



Fig. 7: Testing quality of hardened concrete with rebound hammer.

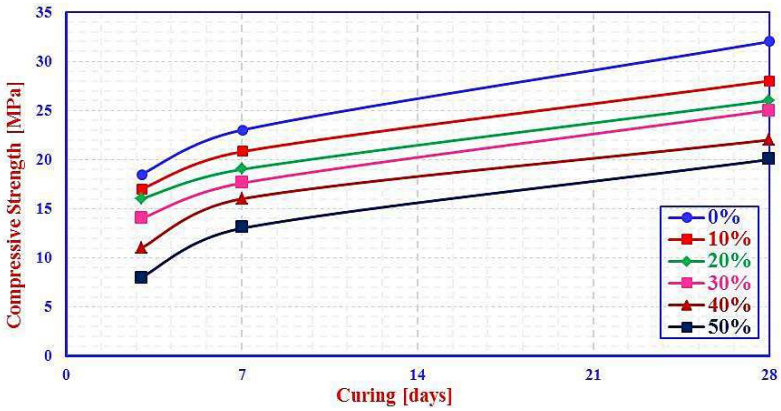


Fig. 8: Strengths of the POS's rebound hammers on various curing days.

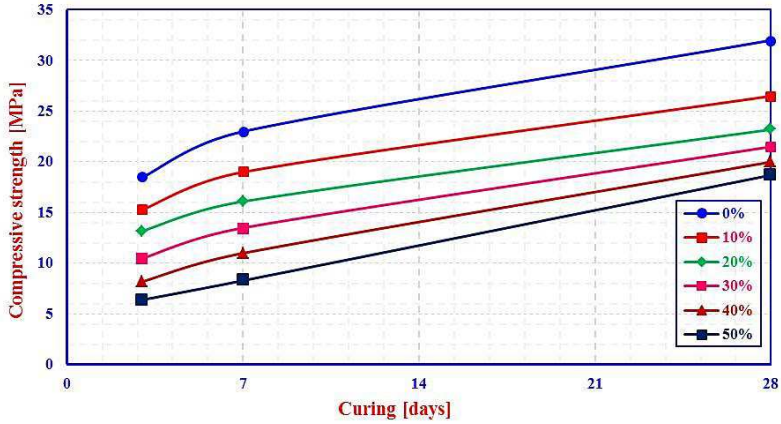


Fig. 9: Strengths of the Pumice's rebound hammers on various curing days.

3.4 Compressive strength test

Testing in simple compression is now the most used technique for determining the strength of concrete. With strengths of over 33.2 MPa and 32.0 MPa, respectively, the strongest concrete was 7.6 MPa and 8.8 MPa less than the control. Additionally, it included pumice replacement and a 10 % POS. The compressive strengths at certain ages of 3, 7, and 28 days are shown in Fig. 11 and 12. A different category, such as 0 percent POS, is displayed every three bars. The use of 0 % pumice is comparable to that of 10 % POS, 10 % pumice, etc. The compressive strength of the concrete specimen and the percentage of LWA (POS and pumice) are negatively correlated, which means that as the percentage of LWA (POS and pumice) rises, the cube strength of the concrete sample declines.

It is also obvious that the strongest concrete is that which contains 0 % LWA; in addition, when LWA increasingly replaces coarse aggregate, the strength of concrete steadily decreases. The fact that LWA materials are supposed to be weaker and lighter than typical coarse aggregate may help to clarify the situation. Additionally, if the percentage of LWA added increases due to the LWA's irregular shapes, the strength of the concrete may decrease. The maximum compressive strength, 40.8 MPa on average, is found in coarse aggregate with 0 % LWA (Control). The greatest compressive strength in 28 days with 10 % POS is 33.20 MPa and 10 % pumice, and 32.0 MPa when coarse aggregate is replaced with LWA (POS & pumice). As a result, the results shown in Fig. 11 and 12 satisfy the structural LWC requirement. According to the specification [1], structural LWC has a compressive strength of 17.0 MPa which is minimum for a period of 28 days. Fig. 10 shows the compressive strength test on concrete cubes.



Fig. 10: Compressive strength test on concrete cubes.

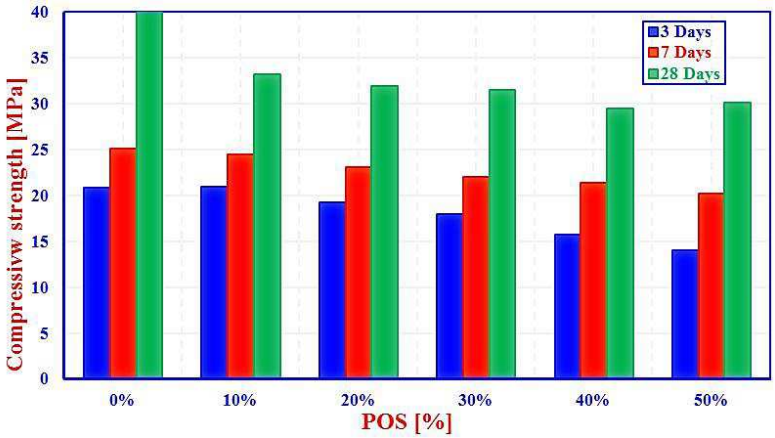


Fig. 11: Compressive strengths of different % of POS.

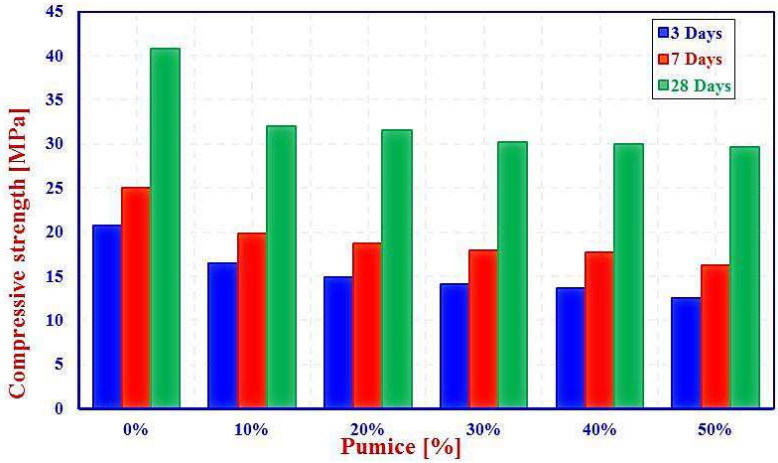


Fig. 12: Compressive strengths of different % of pumice.

4 Conclusion

After the series of lab tests, concrete with crushed palm oil shell and pumice (LWA) as CA will have lesser compressive strength of LWA associated with the NWC. Based on the experimental outcomes, the following conclusions are drawn:

1) Pumice and POS have specific gravities of 1.15 and 1.06, respectively, indicating that LWA are roughly 60 % lighter than typical coarse aggregates.

2) As the replacement of the LWA (POS & pumice) improved, it decreases the concrete's workability because of the form of the LWA's.

3) The compressive strength of LWAC is lower than the NWC, but the difference is small, which is around 7.6 % to 8.8 %.

4) Compared to standard gravel aggregates, LWA (POS and pumice) has a much higher 24-hour water absorption capacity of 33.30 and 46.23, respectively.

5) As the percentage of LWA replacement rises, the workability of the concrete decreases (POS and pumice).

6) The compressive strength of LWA concrete specimens varied depending upon the percentage of LWA in the sample, with concrete containing 10 % LWA having the highest compressive strength and concrete containing 50 % LWA having the lowest. The amount of LWA (POS and pumice) and the curing period, which together make up the samples' strength, allowed for the achievement of the minimal structural requirements for light weight concrete.

5 Future challenges

The following future scope shall be undertaken as future challenges of this current research:

1) Durability studies on light weight aggregate concrete in the environmental aspect.

2) Experimental studies on light weight aggregate concrete structural members with various percentages of POS and pumice as parametrical study.

3) Experimental investigation on structural behaviour of structural components such as beams, slabs and columns with light aggregate concrete in the view of environmental sustainability.

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