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Experimental Study on Strength and Buoyancy of Lightweight Concrete Containing Sustainable Materials

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Abstract: To meet current demand, the building industry is focusing on sustainable alternative materials to conventional concrete. Lightweight concrete is becoming increasingly popular as a viable solution for meeting structural, economic, and environmental requirements. The study was aimed at producing pontoons measuring 500mm x 500mm x 100mm using sustainable materials such as LECA Ball and PVC pipes that are capable of floating on water and to identify the appropriate mixing ratio of concrete materials to produce lightweight concrete that has high compressive strength and buoyancy. A total of 36 samples for the cube test and 6 samples for the pontoon were used as test material to meet the objectives of this study. Concrete cube specimens were tested after the curing period on the 7th and 28th days. While the pontoon concrete was tested on the 28th day for buoyancy. The results from the test that have been conducted show that the concrete mix that produces the highest average compressive strength is mix proportion 1: 1: 2, which is 13.997 N/mm^2, while for the buoyancy test, the mix proportion that can accommodate the highest maximum load is 1.5: 1: 2, i.e., 6.788 kg.

Keywords: Sustainable, Pontoon, Concrete, Lightweight Concrete, LECA, PVC, Compressive Strength, Buoyancy

1. Introduction

Concrete has been widely used in the construction industry for decades due to rising construction demand and massive infrastructure growth around the world. The global demand for concrete is currently expected to be about 10 billion tonnes per year (Meyer, 2009). If one assumes that concrete is 70% aggregate sand and uses 300 kg/m^3 cement, the industry consumes about 1.2 billion tonnes of cement and 7.5 billion tonnes of aggregates per year. In addition, concrete manufacture requires high energy consumption, and its destruction produces significant volumes of construction waste. Lu et al.

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(2013) emphasizes the importance of energy use in the industrial sector, where any energy savings can have a significant environmental impact. A great demand for aggregates created a scarcity of natural coarse aggregates in many developing countries, respectively. Therefore, to solve the problems related to the scarcity of natural aggregates, engineers have produced Lightweight aggregate (LWA) as a replacement for natural coarse aggregate in concrete.

According to the current study, lightweight aggregates can be classified as natural or artificial, such as pumice, scoria, and volcanic aggregates, expanded blast-furnace slag, vermiculite, and clinker aggregates (Tiong et al., 2020). Lightweight expanded clay aggregate (LECA) is a type of lightweight aggregate manufactured through a series of processes from naturally available clay. In the manufacturing process, the clay is burnt and pelletized in a rotating kiln at a very high temperature of roughly 1150 °C. Because of its physical features, adopting LECA in LWC has several advantages, including higher strength, reduced density, better thermal and sound insulation, cost savings in construction, and so on. It has been claimed that a structural lightweight aggregate concrete made by replacing coarse aggregate with LECA may attain cube compressive strengths ranging from 35 MPa to 47 MPa and densities ranging from 1760 kg/m^3 to 1900 kg/m^3 (Yew et al., 2015).

In research by Ye (2017), PVC is one of the world's most commonly consumed plastics. Recently, there has been a renewed interest in tonnes of worldwide PVC waste. In this experiment, PVC pipe will be inserted in a pontoon measuring 500mm x 500mm x 100mm to create an air void in the pontoon that can float on water. As a result, the post-consumer phase of PVC generates a considerable amount of trash, which has accumulated and could cause serious environmental and human health hazards if not adequately treated or managed. For example, landfilling plastic wastes may result in issues such as land occupation and soil pollution, whereas burning or cremation of PVC wastes produces poisonous compounds (dioxin) that are harmful to human health. A more appropriate technique to treat PVC post-consumer wastes, such as recycling, can recover PVC material for secondary production, which not only reduces the demand for new material and energy but also avoids environmental problems (Sadat-Shojai & Bakhshandeh, 2011). The sustainability of the material, namely PVC pipe, which is used as a flotation system, makes the structure environmentally friendly and can reduce the use of natural resources while protecting the environment.

2. Methodology

This chapter will go over the implementation of the lightweight concrete study. The objectives described in chapter one is the goals of this study. Research methodology should be seen as a measure or approach for achieving all of the objectives for which scientific research activities are carried out. Slump tests, concrete compressive tests, and buoyancy tests are used to evaluate lightweight concrete. Furthermore, the test results were compared in order to establish the strength and workability of lightweight expanded clay aggregate (LECA) as a replacement for coarse aggregate in concrete mixes.

2.1 Experimental procedure flowchart

Figure 1 shows the experimental procedure flowchart that explains how the study should proceed in order to obtain the results and the discussion.

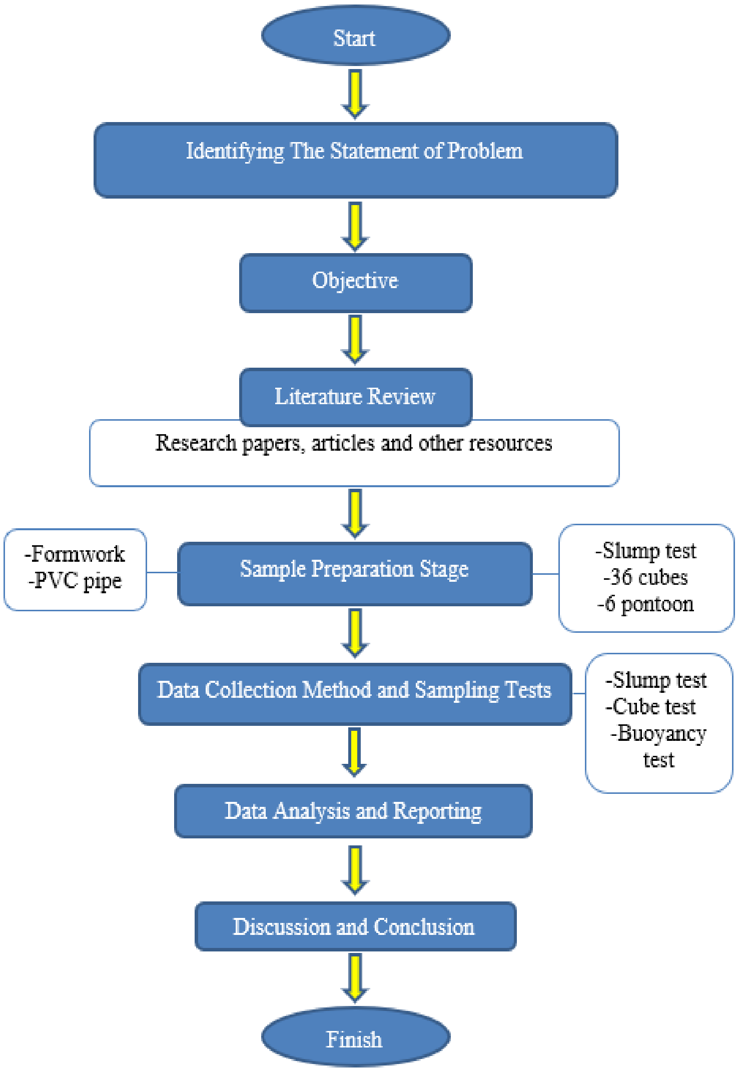

Figure 1: Experimental Procedure Flowchart

2.2 Study instrumentation

According to Sheriff (2014), a researched instrument was a procedure used to design, test, and apply instruments or materials to generate studied results. A researched agency was a measured tool utilized in the study, such as interview forms, questionnaires, and data gathering. The data-gathering device was employed in this investigation. A total of 36 cubes and six pontoons were produced with different ratios. Each concrete mix created must undergo a slumped test to assess its workability. A slumped cone mould, scooped, steel tamping rod, baseplate, and tape measure were required for the slumped test. The steel cube measures 150mm long x 150mm broad x 150mm high, iron rods measured 16mm and 600mm long, and grease oil was used to prevent concrete from sticking within the mould. The cube had been evaluated for compressive strength with a compressive strength machine, and the pontoon had been tested for buoyancy. Weighing equipment was used to determine the cube's weight and the maximum load the pontoon could support before being entirely immersed. The concrete cube test form was used to record the concrete strength test findings. After compiling all of the results, comparisons were made to establish the ideal concrete ratio for producing lightweight concrete with good compressive strength and buoyancy.

3. Results and Discussion

Specimens were cured, and all cube tests were performed on the 7th and 28th days, while the buoyancy test was performed on the 28th day. For the cube test, there were 36 cubes prepared using six different mix ratios, while the buoyancy test used six pontoons with different mixing ratios. Experimental results were compared to determine concrete strength and buoyancy. This research focuses on the manufacture of lightweight concrete with complete structural efficiency that contains aggregates from the other end of the spectrum, which are normally made using expanded clay. This structural lightweight concrete categorization is based on a minimum strength: the 28-day cube compressive strength should not be less than 17 MPa, according to ASTM C 330 (2500 psi). The density of such concrete (determined in the dry condition) should not exceed 1840 kg/m^3 and is commonly between 1400 and 1800 kg/m^3. The water-cement ratio that has been used is 0.60. The mixing ratios used for the cube and buoyancy tests were 1: 2: 3, 1.5: 1: 2, 1.5: 1: 3, 1: 2: 2, 1: 2: 1 and 1: 1: 2.

3.1 Results and Discussions

Table 1 shows the slump test. For a 1: 2: 3 concrete mix ratio, the slump value is 102 mm; for a 1.5: 1: 2 ratio, the slump value is 120 mm, while the 1.5: 1: 3 slump value is 115 mm, the slump value for 1: 2: 2 is 105 mm, while the slump value for 1: 2: 1 is 130 mm and finally the slump value for 1: 1: 2 is 128 mm. All the sixth compositions produced a shear slump as a type of slump. According to Koehler and Fowler (2013), the only type of slump permissible under ASTM C143 is frequently referred to as the ‘true slump’, where the concrete remains intact and retains a symmetric shape.

Table 1: Slump Test Result

Mix Proportion	Slump (mm)	Type of Slump	Description
1:2:3	102	Shear Slump	Accepted
1.5:1:2	120	Shear Slump	Accepted
1.5:1:3	115	Shear Slump	Accepted
1:2:2	105	Shear Slump	Accepted
1:2:1	130	Shear Slump	Accepted
1:1:2	128	Shear Slump	Accepted

Test results for the strength of concrete cubes are presented in Table 2 and Table 3. Overall, the test results for six different concrete mix ratios showed an increase in cube strength on day 7 and day 28 except for the 1: 2: 1 ratio, which showed a decrease in average compressive strength on day 28, which was 8.3 N/mm^2 compared to 9.377 N/ mm^2 on the 7th day.

Table 2: Compressive Strength Results on the 7th Day

Mix Proportion	Cube Mark	Density kg/m^3	Average Density kg/m^3	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1:2:3	A1	1646	1664.7	2.31	2.333
	A2	1690.4		2.12	
	A3	1657.8		2.57	
1.5:1:2	B1	1612	1608	9.50	9.023
	B2	1601.5		9.65	
	B3	1610.4		7.92	
1.5:1:3	C1	1440	1461.7	5.27	5.733
	C2	1471		5.73	
	C3	1474		6.20	
1:2:2	D1	1574.8	1577.8	5.56	5.423
	D2	1572		5.20	
	D3	1586.7		5.51	

1:2:1	E1	1823.7	1818.3	9.12	9.377
	E2	1812		8.38	
	E3	1819.3		10.63	
1:1:2	F1	1539.3	1538.9	7.63	8.783
	F2	1529		10.49	
	F3	1548.4		8.23	

Table 3: Compressive Strength Results on the 28th Day

Mix Proportion	Cube Mark	Density kg/m^3	Average Density kg/m^3	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)
1:2:3	A4	1628	1634.5	5.18	5.74
	A5	1641.5		5.76	
	A6	1634		6.28	
1.5:1:2	B4	1606	1606.2	13.46	13.943
	B5	1607.4		14.32	
	B6	1605.3		14.05	
1.5:1:3	C4	1577.8	1562.5	12.79	11.657
	C5	1554		12.68	
	C6	1555.6		9.50	
1:2:2	D4	1515.6	1512.1	7.91	9.043
	D5	1512.6		9.49	
	D6	1508		9.73	
1:2:1	E4	1631	1636	8.59	8.300
	E5	1632.6		8.07	
	E6	1644.4		8.24	
1:1:2	F4	1832.6	1811.3	14.65	13.997
	F5	1807.4		12.30	
	F6	1794		15.04	

The line graph in Figure 2 shows the average compressive strength of concrete cubes for mix ratios of 1: 2: 3, 1.5: 1: 2, 1.5: 1: 3, 1: 2: 2, 1: 2: 1, and 1: 1: 2 with a water-cement ratio of 0.60 over a curing period of 7 and 28 days. On the 7th day, the maximum average compressive strength was 9.377 N/mm^2 for a 1: 2: 1 mix proportion and the lowest was 2.333 N/mm^2 for a 1: 2: 3 mix proportion. On the 28th day, the maximum average compressive strength was 13.997 N/mm^2 for a mix proportion of 1: 1: 2, and the lowest was 5.74 N/mm^2 for a mix proportion of 1: 2: 3. On the 28th day, five mix proportions demonstrated an increase in compressive strength based on compression test findings. The compressive strength of the 1: 2: 1 mixture ratio, on the other hand, decreased from 9.377 N/mm^2 on the 7th day to 8.3 N/mm^2 on the 28th day. When uniform compressive stress is applied, particles move closer together to fill vacancies, and cracks occur on concrete at lower loads. This is the reason why the compressive strength of a cube decreases as its size grows. The density of concrete reduced as the proportion of replacement rose, although its workability improved (Yew et al., 2020). Compressive strength, split tensile strength, and flexural strength decreased as the amount of light expanded clay particles increased. In research from Rashad (2018), when compared to traditional coarse aggregates, the round shape of LECA resulted in a loss in binding strength with the surrounding concrete.

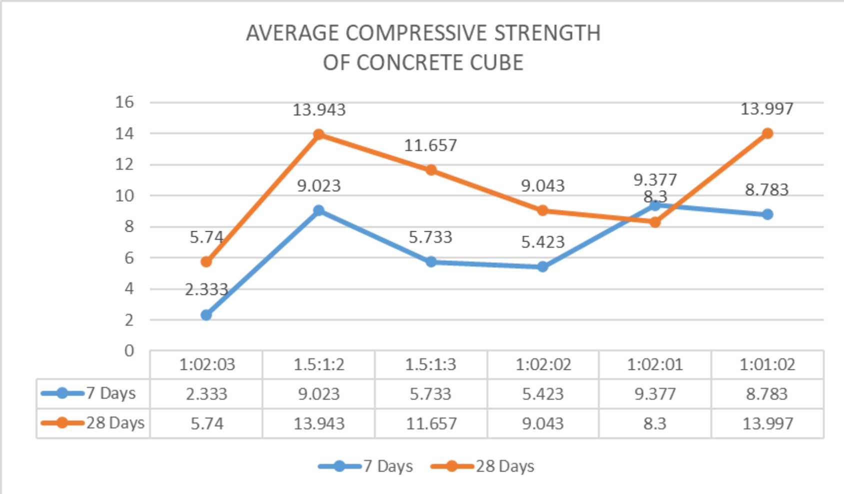

Figure 2: Line Graph for Average Compressive Strength of Concrete Cube

The buoyancy test results for six different mixtures are presented in Table 4. A mix ratio of 1.5: 1: 2 (6.788 kg) is the highest maximum weight that a pontoon can support before sinking. The pontoon's lowest maximum load is 4.058 kg, which is a mixed percentage of 1: 2: 1.

Table 4: Buoyancy Test Result

Mix Proportion	Weight of Pontoon (kg)	Buoyancy Force (N)	Density (kg/m^3)	Max Load (kg)
1:2:3	19.342	189.68	773.68	5.992
1.5:1:2	19.848	194.64	793.92	6.788
1.5:1:3	17.548	172.1	701.92	6.192
1:2:2	19.610	192.3	784.4	4.708
1:2:1	21.968	215.43	878.72	4.058
1:1:2	17.536	171.97	701.44	6.304

Figure 3 depicts the results of the buoyancy test. Based on the test results, the pontoon's maximum load capacity is 6.788 kg, with a buoyancy force of 194.64 N and a density of 793.92 kg/m^3. While the pontoon's lowest maximum load is 4.058 kg for a 1: 2: 1 mix proportion, the buoyancy force is 215.43 N, and the density is 878.72 kg/m^3. This clearly implies that objects with a high density will reduce the maximum load that the pontoon can support. Weight is a measure of the force of gravity pulling down on an object, whereas buoyant force pushes up on an object (Buoyancy, 2021). Which force is greater affect whether an object sinks or floats. Furthermore, the maximum load value is 5.992 kg, the buoyancy force is 189.68 N, and the density is 773.68 kg/m^3 for the mix proportion 1: 2: 3. The maximum load value is 6.192 kg, with a buoyancy force of 172.1 N and a density of 701.92 kg/m^3 for a mixed percentage of 1.5: 1: 3. The maximum load value for mix proportion 1: 2: 2 is 4.708 kg, buoyancy force 192.3 N, and density 784.4 kg/m^3. The maximum load value for a mix proportion of 1: 1: 2 is 6.304 kg, with a buoyancy force of 171.97 N and a density of 701.44 kg/m^3. According to Moebs et. al. (2016), an object will float if its average density is less than that of the surrounding fluid. The reason for this is that a greater density fluid contains more mass and so more weight in the same volume.

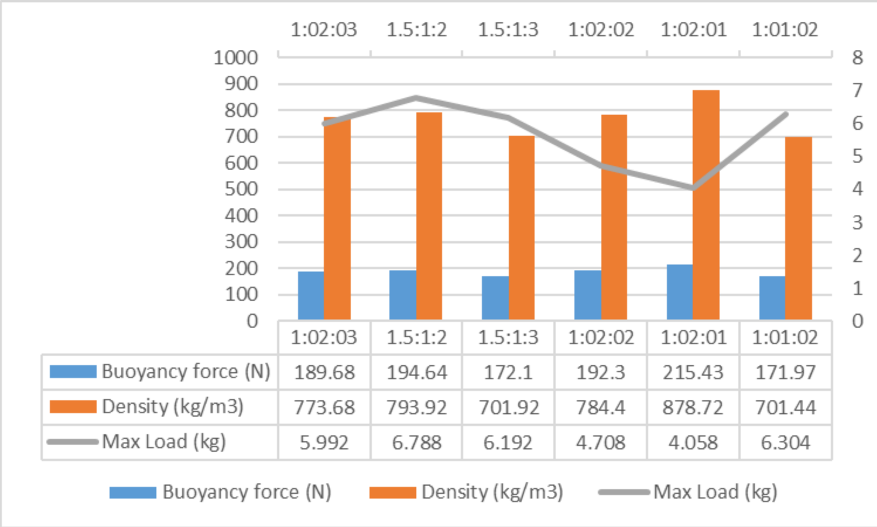

Figure 3: Clustered Column for Buoyancy Test

4. Conclusion

According to the study's findings, the first objective was achieved which is to produce pontoons measuring 500mm x 500mm x 100mm using sustainable materials such as LECA Ball and PVC pipes that can float on water. The concrete pontoon floats on the water due to its high buoyancy and precise position of the metacenter point. The weight applied to the pontoon's upper surface up to a maximum load of 6.788 kg before it was submerged in water for a mixing ratio of 1.5:1:2 was recorded. The concrete compressive strength test revealed that all six total combinations had compressive strengths of less than 17 MPa. According to ASTM C 330, the 28-day cube compressive strength of structural lightweight concrete should not be less than 17 MPa, and the density of such concrete should not exceed 1840 kg/m^3, and is commonly between 1400 and 1800 kg/m^3. The resulting mixture does not match the ASTM C 330 standards and is not suitable for use in structural concrete. In a study of all lightweight concretes prepared, the maximum average compressive strength achieved only 13.997 N/mm^2 after 28 days of curing with a mixing ratio of 1:1:2. The second stated objective, according to the data gathered throughout this investigation, was not accomplished.

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