Light-weight non-load bearing blocks using expanded polystyrene beads

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LIGHTWEIGHT NON-LOAD BEARING BLOCKS USING EXPANDED POLYSTYRENE BEADS

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ABSTRACT. Lightweight blocks can reduce time and cost of masonry wall construction. Several investigations are being carried out to produce lightweight cement blocks. Some of them are autoclaved aerated concrete, use of lightweight aggregates, use of fly ash, etc. In general, partition cement blocks are non-structural elements that do not carry any load. In this research project, an attempt was made to utilize polymers, specifically Expanded Polystyrene, in the place of aggregates in concrete to manufacture non-load bearing blocks. Replacing aggregates with Expanded Polystyrene can make the blocks lightweight. The blocks are required to bear a minimum of 1.2 N/mm^2 and have a density that is less than 1000 kg/m^3, so that it can be easy to handle. The water absorption should also be less than 12%. These blocks would then be tested for density, compression and water absorption to ensure that they reached the requirements of a non-load bearing masonry unit. Solid blocks of dimensions 390 mm × 100 mm × 190 mm were produced, using modified mix designs, by considering previous research studies. Tests carried out on the developed blocks were compared with control samples obtained from certified cement block manufacturers. The results showed that the blocks containing the suitable EPS mix had a 28-day compressive strength of 3.7 N/mm^2, dry density of 940 kg/m^3 and a water absorption of 0.7%. These values satisfy the requirements of minimum compressive strength, density and water absorption. The study shows that non-load bearing lightweight blocks has potential to replace traditional blocks.

Keywords: Lightweight Blocks, Expanded Polystyrene, Density, Compressive Strength

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INTRODUCTION

Cement blocks are an important element in civil infrastructure. They are used for a number of reasons involving partitioning in buildings, boundaries of land premises and external and internal wall constructions. Concrete blocks are essential for a building as they provide privacy, shelter and protection from external forces or matters to the users of the building.

There are two kinds of concrete blocks: load bearing and non-load bearing blocks. Load bearing blocks can carry loads that are transferred from elements above it such as beams and/or slabs in addition to its self-weight. However non-load bearing blocks do not carry any external loads, except for its self-weight. This research project investigates how a lightweight non-load bearing block can be made.

During construction of any structure, time is an important factor. It is important to ensure that all tasks are carried out efficiently to prevent delays. One of the most time consuming activities include the construction procedure of partition walls in a building. Workers have to move and lift the blocks; the weight, of nearly 15 kg per block, slows the workers' speed down. The heaviness also makes them tired more frequently which affects the productivity of the job as a whole. Therefore it will take longer to build the wall; the increase in time taken, increases the cost incurred for the job. Transportation of the blocks from one place to another is also difficult, time-consuming as well as costly in this sense, both manually and by vehicle. Labour and weight lifting machinery, such as cranes would take a longer time and a significant amount of energy should be spent to move blocks from storage to place of construction. Vehicles would also take a longer time to transport blocks from supplier to site, which consumes both time and money.

For the manufacturing of all man-made artificial products, Earth's limited supply of resources is being used up. Aggregate from rock found in the soil is one such resource. Since concrete is now a widely used product for many structures, the aggregate left for the future generations is diminishing gradually. Aggregates are taken from quarry sites, which means mountains belonging to the country are broken down and destroyed. This causes a massive negative effect on climate and it drastically changes the groundwater patterns in the soil which affect humans and flora and fauna alike.

Expanded polystyrene (EPS), on the other hand, is a commercially available product; it is also much more easily accessible than other types of man-made aggregates. EPS is a non-biodegradable product, meaning that if it were thrown out into the environment, nature would not decay it [3].Therefore it is important to reuse EPS as much as possible, to avoid it ending up in landfills. The main use of EPS nowadays is for packaging fragile goods; after this purpose EPS is not put to any use and ends up as waste. Making use for such EPS in a product such as a cement block could help reduce the amount of EPS ending up in landfills, thus reduce a certain amount and type of waste and improve sustainable practices.

For this reason, it would be of immense value to the industry if concrete blocks were lighter in weight using EPS as its aggregate. There are several ways of making the blocks lighter. This research investigates how a selected polymer material was used in concrete by replacing one of its main components, namely the coarse aggregate. The EPS that is currently being produced in the world needs to remain in the industry as a recycled material instead of being discarded after one use. With the gradual reduce of natural resources, EPS used in place of aggregates would help preserve resources for future generations. This research shows that these problems can be overcome with a lightweight non-load bearing block that uses EPS beads in place of aggregate.

EXPERIMENTAL INVESTIGATION

Materials

Ordinary Portland cement conforming to SLS 107: 2008 equivalent to BS EN 197, was used to produce test samples. River sand was used as fine aggregate in all the mixes excluding the trial mix which was done without any fine aggregate, i.e. sand.

In a previous research [4], it was mentioned that polyethylene (PE) was used as a replacement for fine aggregate. However, if this were to be used in this study, large amounts would be required which would be both difficult to obtain and also uneconomical. Glass bubbles were another polymer that was suggested in place of fine aggregate. However, this would require shipping from overseas which is risky due to the highly variable time of arrival; hence it too was opt out.

Polymer materials, to replace one or both of the aggregates were researched upon where fibre-reinforced polymer (FRP), PE: high density polyethylene (HDPE) and low density polyethylene (LDPE) as well as EPS) were considered. Replacement of a major component of concrete, namely the aggregates is one of the many ways of making lightweight concrete.

FRP is a good alternative as it has been used in another past study done in the year 2016 [8]. However, its characteristic of absorbing water from the surrounding mortar could cause undesirable effects like cracking and shrinkage. It is also difficult to obtain FRP in Sri Lanka and requires shipping from overseas.

The past research [4] pointed towards the use of PE, more specifically HDPE and LDPE as replacements for aggregates. The partially replaced PE blocks, according to past research studies, also did not satisfy the required density in this case which has a maximum value of 1000 kg/m^3. However, blocks containing PE with proportions of 6% and 9% had shown evidence of cracking due to the hydrophobic properties. LDPE and HDPE were suggestive of a good option as they were plentifully available in Sri Lanka in the form of shopping bags and plastic items, like children’s toys and plastic plates and cups. However, if these materials were selected, large amounts would be required to fulfil the required volume. Therefore it was clearly an uneconomical choice, thus proving that HDPE and LDPE were not the best aggregate alternatives for this case.

According to another past study [1] waste EPS used with resin as a coarse aggregate replacement produced lightweight concrete. The samples with full replacement of EPS produced compressive strengths that were well above the requirement for this research which is 1.2 N/mm^2. Also this research showed that the higher the EPS ratio, the lower the water absorption. EPS on the other hand was readily available in larger stores of Sri Lanka and cost a reasonable price. Therefore EPS was selected as the final replacement polymer for coarse aggregate in this study.

Two size combinations, of 5 mm and 10 mm or 6 mm and 12 mm diameter balls, were chosen to imitate the matrix like structure formed by varying sizes (within a defined range) of aggregates. These sizes were selected to conform to the maximum allowable aggregate size in cement blocks which is 12.5 mm in diameter [5]. These distinct sizes were difficult to find and after much searching it was determined that the research would use EPS beads of sizes ranging from below 10 mm to about 1.5 mm in diameter. These values still satisfied the necessary range and therefore it was selected.

Three control blocks were purchased from a Sri Lanka Standards certified commercial manufacturer. These blocks were identical and of size 390 × 100 × 190 mm. The composition of a conventional block from the market is 1: 3: 4 (by volume) of cement to chips to quarry dust with a water to cement ratio of 0.5.

Test Specimen

With reference to a past conducted study [5], it was determined that this research required a standard block size. Thus selecting the standard block size of 390 × 100 × 190 mm to adhere to the minimum compressive strength and maximum water absorption stated in the SLS 885 [6].

Each mix was carried out in the following manner. The block moulds were cleaned, oiled with mould oil and tightened well to prevent leaks. The needed amounts of cement, sand, water and EPS were weighed and retained in containers. The concrete mixer was kept in a spacious flat area. The sand and cement were placed inside and mixed thoroughly for about 3 minutes. The water was added to the mix. The EPS was added after the water because without the moisture, the EPS tended to fly out of the mixer with the force of the mixing materials. The mixing was continued until a well-mixed, uniform mixture was formed. The concrete was then filled into the moulds in 3 layers. Each layer was tamped using a square-based tamping rod, 35 times before the next layer was added. The exterior of the moulds were then cleaned up and the filled moulds were placed in a sheltered location. The casted elements were de-moulded after 24 hours and they were placed in a curing tank where they cured until the time of testing. Details of the mixes are given in Table 1.

Table 1 Details of EPS concrete mixes

MIX	WEIGHT PER CUBIC METER, kg/m^3				WATER CEMENT RATIO
	CEMENT	SAND	WATER	EPS	
1	550	132	154	13.5	0.28
2	550	132	275	13.5	0.50
3	550	132	248	13.5	0.45
4	550	132	220	13.5	0.40

Experimental Investigation

Steel block moulds were custom made to the precise inner dimensions of 390 × 100 × 190 mm. Each mix was prepared to fill 3 blocks which were to be tested at 28 days.

The tests for compression, water absorption and density were carried out, in order to adhere to the main objective of this research according to a past research [5]. This was necessary as the compression of the blocks determine their overall suitability as a non-load bearing concrete block.

The concrete blocks were taken out of the curing tank two days prior to compression testing and weighed for its wet weight. They were then left to dry for 2 days (48 hours), until the day of testing. Before testing the dry block is weighed to measure its dry weight. The volume is known as the moulds were of standard dimensions. Thus the wet and dry densities were calculated.

The compressive strength of the blocks were checked at 28 days of age. This was done by using a compressive strength machine. The block was placed on the platform and the load was applied at a rate of 1.5 – 2 kN/s. After being tested, each block was broken manually in half to observe the dispersion of EPS among the mortar.

The water absorption must also be below the maximum of 12% as stated in the SLS 885 [6]. This was checked according to ASTM C642-82, after the mix was stabilized. As mentioned in a research done [4], the water absorption test was done as follows. The block was thoroughly dried. For this a block should ideally be placed in a hot air oven at a temperature range of 100-110 °C. A reference [4] suggests using a temperature of 60 ℃ as any temperature higher than that would cause the EPS to evaporate. However, for this research, the blocks were left in a dry location for 2 days to ensure that water in the block would evaporate. After the block was dry, it was immersed in water and its weight was measured at regular intervals until the weight measurement became constant. The absorption at 30 minutes and the final absorption will give an idea of the quality of concrete and the required water absorption for use respectively. If the water absorption at 30 minutes is less than 3%, it shows that the concrete is of good quality according to [4]. A final water absorption of 12% or less shows that the block is suitable for use as a non-load bearing block according to [6].

A sieve analysis test was unnecessary in this study due to the fact that the EPS balls came in fixed sizes and were used as they were without modifications.

RESULTS AND DISCUSSION

Mixes

A summary of the compressive strengths, wet densities and dry densities values are presented in Table 3.

Table 2 Strengths and densities of EPS concrete mixes and control specimen

MIX	ELEMENT	WET DENSITY kg/m^3	DRY DENSITY kg/m^3	COMPRESSIVE STRENGTH N/mm^2	AGE TESTED day
Control	Block	2001.80	1936.12	6.56	28
Trial	Block	318.49	288.80	0.18	7

1	Block	-	859.65	1.38	28
2	Block	-	413.86	0.17	28
3	Block	955.47	947.37	4.19	28
4	Block	948.27	941.97	3.71	28

Mix 1 proved to be very difficult to mix. The mixture was dry and formed large clumps roughly 80-100 mm across. The EPS stuck to the outside of these clumps which simply rolled around inside the mixer. Manual force was required to break these large clumps into smaller ones in order to let EPS distribute among the mortar better. This showed that Mix 1 with the water to cement ratio of 0.28 was not suitable for a concrete non-load bearing block mixture. The cross section of the blocks also showed that the EPS had poorly distributed among the grout. This showed that although the casted elements satisfied both the density and the compressive strength requirements, the coarse aggregate did not distribute appropriately among the cement. Therefore the Mix 1 was not suitable for use. A specimen is shown in Figure 1.

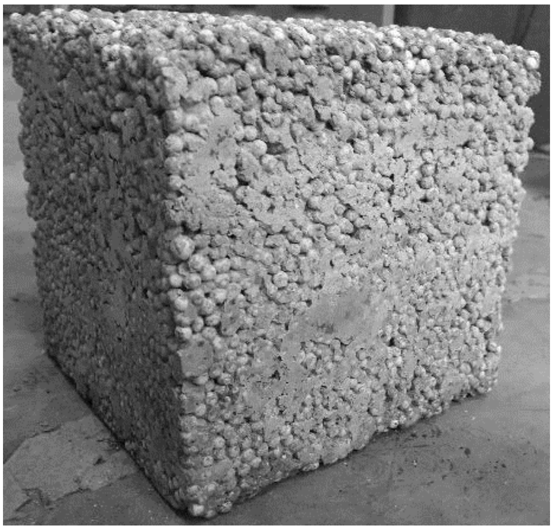

Figure 1 Specimen of Mix 1

Mix 2 was casted using a water to cement ratio of 0.5 which is the ratio used in conventional blocks as well. This mix had EPS distributed among the mortar better than that of Mix 1. However the water content to too high, even though the EPS mixed throughout, some of it floated. The consistency of the mix is shown in Figure 2. The cement and sand also segregated inside the mixer, causing the casted blocks to have a clear layer of grout at the bottom of them as shown in Figure 3. This layer formed due to the large water to cement ratio. Once the concrete was placed in the moulds, the watery grout sunk to the bottom of the mould.

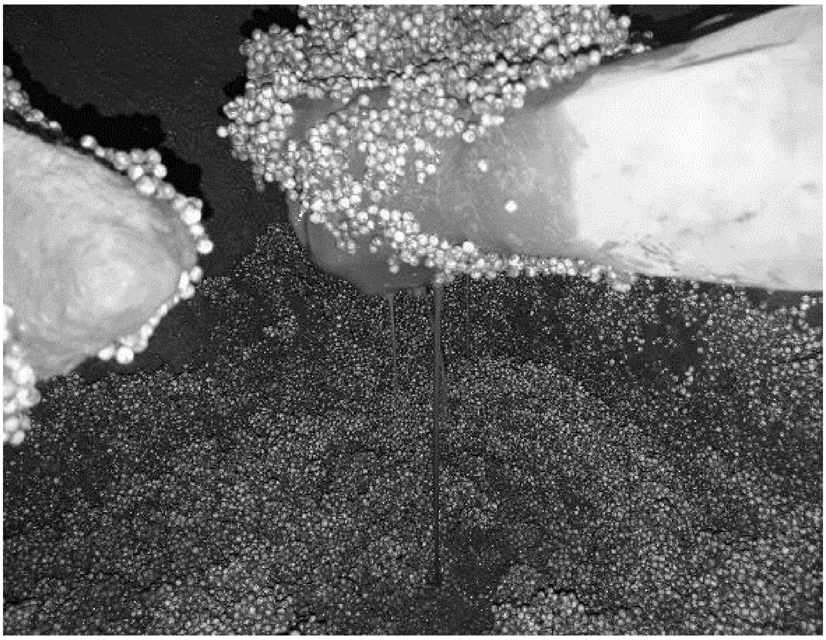

Figure 2 Consistency of Mix 2

The blocks of Mix 2 also looked very fragile and EPS easily separated from the rest of the block with the force. The casted blocks had a very low density, well satisfying the requirement of a maximum of 1000 kg/m^3. The compressive strength was very low and below the necessity of 1.2 N/mm^2 deeming it unsuitable for use as a non-load bearing block.

Figure 3 Specimen of Mix 2

Mix 3 which was mixed using the ratio of 0.45 of water to cement also showed that the mix was rather wet to the point of being slurry-like. The mixture was uniform and proved to be much better than that of Mix 2. It did segregate to some degree, yet not as much as Mix 2 did. The casted elements were much sturdier than those of Mix 1 or 2. The lower water to cement ratio of 0.45 made this mix much more suitable for use in concrete blocks. This batch produced an acceptable density and compressive strength, however its distribution of EPS among the grout was unsatisfactory as seen in Figure 4.

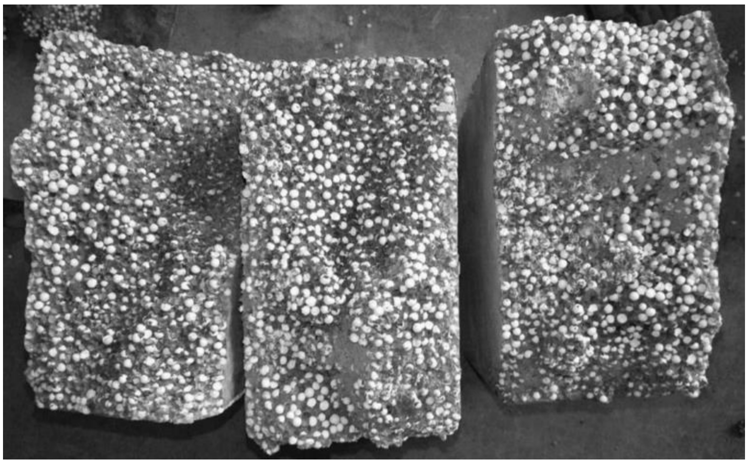
Figure 4 EPS distribution in blocks of Mix 3

Mix 4 was a good mix consisting of the water to cement ratio of 0.40. The mix was light, non-bulky and very easy to handle. It produced a true slump of 70 mm as shown in Figure 5. This mix was the most suitable for the blocks due to the good mixing and also the easy handling of the concrete as it was light.


Figure 5 True slump of Mix 4

The compressive strength values obtained by the blocks of Mix 4 showed that the initial aim of making blocks that floated on water was achieved. Figure 6 shows the blocks floating on water. The compressive strengths showed that the blocks were suitable to be non-load bearing with compressive strengths that were greater than 1.2 N/mm^2 at 28 days. Observing the inside of the block by cutting, showed that the EPS was distributed very evenly among the grout, as seen in Figure 7.

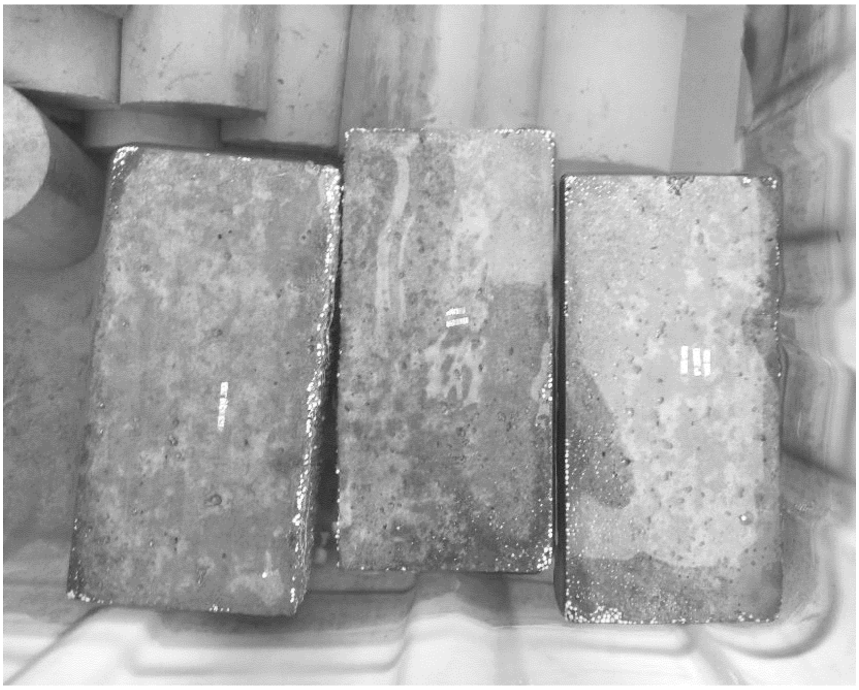

Figure 6 Blocks of Mix 4 floating on water

Figure 7 Even distribution of EPS among grout in blocks of Mix 4

Water Absorption

Mix 4 was appropriate and therefore the water absorption test was conducted on the blocks. The results of the test are shown in Table 4.

Table 3 Water absorption test results of Mix 4

ELEMENT	DRY MASS, kg	WET MASS AT 30 min, kg	ABSORPTION AT 30 min, %	FINAL WET MASS, kg	FINAL ABSORPTION, %
Block 1	7.00	7.01	0.14	7.04	0.57
Block 2	7.32	7.33	0.14	7.36	0.54
Block 3	6.62	6.63	0.15	6.68	0.90

A water absorption at 30 minutes of less than 3% indicates a good quality of concrete according to a study [2]. As stated in the SLS 885 [6], the minimum absorption of a block should be 12%. The average absorption of the blocks of Mix 4 at 30 minutes was 0.143% which is well below the limit of 3% thus proving it is concrete of good quality. The average final water absorption is 0.67% which is less than 12% and hence the block is suitable as a non-load bearing block.

Variation of Compressive Strength

Figure 8 shows how the compressive strength varies with each mix with the control. Generally, with curing the strength increases, therefore theoretically the compressive strengths of, say, a block should be greater at 28 days than at 7 days. After 28 days it is assumed that the strength does not increase any further. The watery consistency of Mix 2 did not allow for the casting of any more than 3 blocks. Blocks of Mix 1 and 2 show that the 28 day strength is a small value. This is assumed to have occurred due to bad curing, where the blocks were not placed in water for the correct assigned time after casting which was 28 days. The blocks of Mix 4 were properly cured for 28 days yet it displays a value that is a little bit lower than that of Mix 3. A reason for this behaviour could be the fact that the used aggregate is spherical in shape and very smooth, which definitely affects the transition zone in the concrete. As this mix was more uniform than that of Mix 3, the smooth texture of the EPS makes the bond between itself and cement paste lower and less strong than if the aggregate texture was rough and jagged. This could also have had a massive effect on the concrete strength at 28 days. Another reason that could explain this behaviour is the temperature of the curing water. It may have increased above 25 °C (the recommended curing temperature) and affected the strength drastically. Although there was a drop in strength in the suitable mix, this was not a problem for the block. This is because the required strength is 1.2 N/mm^2 and the gained strength was already more than three times the value needed. The conventional control specimen has a high strength, which is about two times higher than that of Mix 4 blocks.

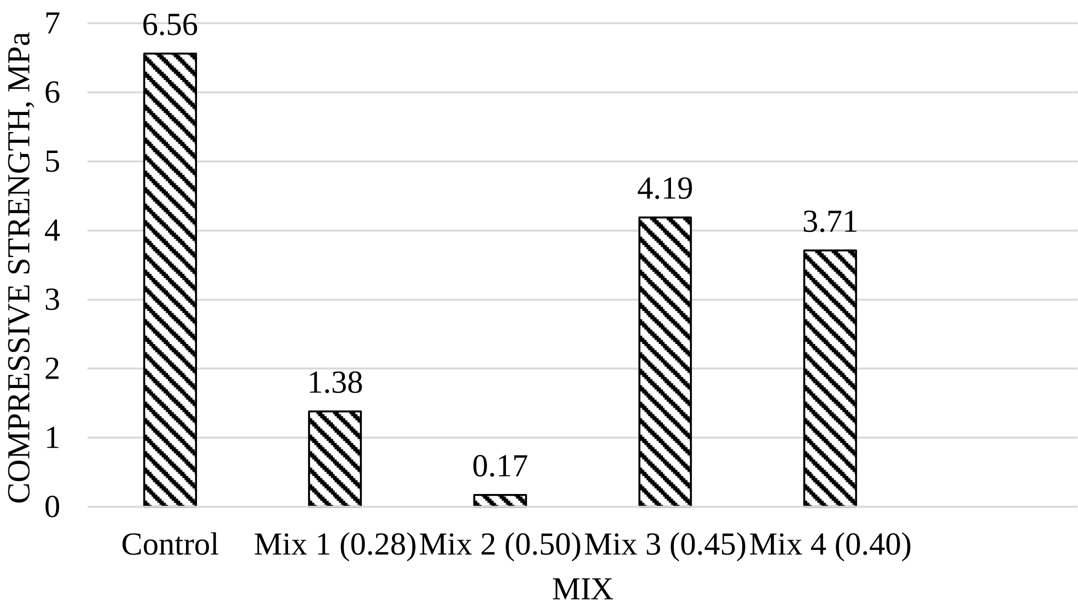

Figure 8 Variation of 28 day compressive strengths in Mixes

Variation of Density

The variation of wet and dry densities (of blocks) in the mixes is shown in Figure 9. As easily seen, the blocks with EPS brought the density down to almost more than half of that of the control. The control consists of chips and quarry dust which are naturally produced materials, which have a higher water absorption than artificially manufactured materials. The control has a larger absorption of water than the mixes, which explains the largest difference between the wet and dry densities. The small difference in wet and dry densities in Mix 3 and 4 indicate the hydrophobic behaviour of EPS. Mix 1 and 2 have the same value for wet and dry density. This is because at 28 days, the measured wet weight was the same as the dry weight. The block was completely dry and had undergone insufficient and therefore incorrect curing.

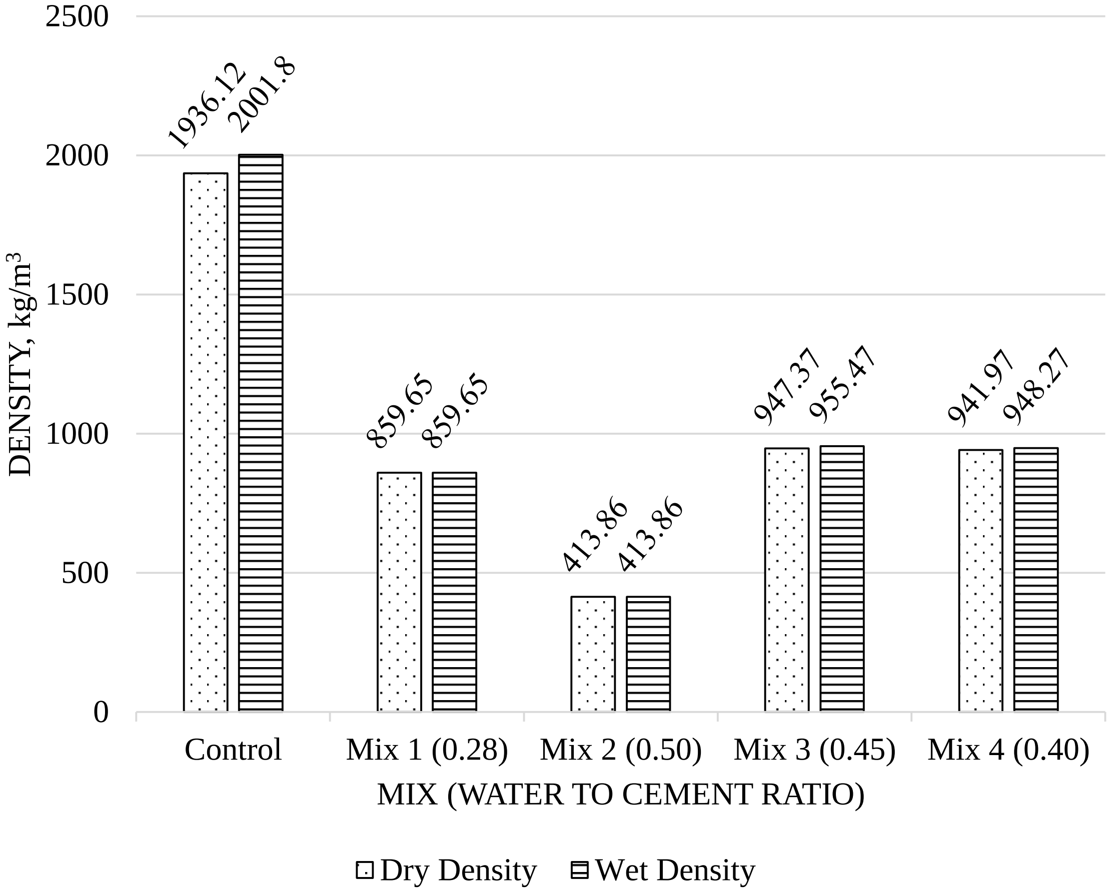

Figure 9 Variation of density in Mixes

Cost Analysis

A conventional block has a composition of cement to ships to quarry dust of 1: 3: 4 by volume. The composition of the lightweight studied block is given in the form of densities in Table 1. The densities of cement, sand and EPS were appropriated as 1442 kg/m^3, 2100 kg/m^3 and 30 kg/m^3 respectively. The costs of materials needed for a single block of dimensions are given in Table 2.

Table 4 Cost analysis of block of 390 × 100 × 190 mm

BLOCK	MATERIAL	UNIT	PRICE PER UNIT (LKR)	QUANTITY REQUIRED (m^3)	PRICE OF MATERIAL PER BLOCK (LKR)	TOTAL PRICE OF BLOCK (LKR)
Conventional	Cement	50 kg sack	930.00	0.00093	24.95	32.35
	Chips	1 cube	6,000.00	0.00278	0.59	
	Quarry Dust	1 cube	5,200.00	0.00371	6.81	
Lightweight	Cement	50 kg sack	930.00	0.00283	12.61	94.14
	Sand	1 cube	13,000.00	0.00047	12.99	
	EPS	Per kg in bulk (≥ 10 kg)	686.00	0.00333	68.54	

From the cost analysis it is clear that the lightweight block is roughly LKR 62.00 more expensive than a conventional block. The EPS costs LKR 810.00 when a single kg is purchased but when purchasing 10 kg or more in bulk, EPS costs LKR 686.00 per kg. In practical situations, the amount of EPS purchased will be much larger than 10 kg if the lightweight blocks were being manufactured, hence the value for 10 kg was selected for the analysis. Although the lightweight block is more expensive initially, it is worth in the long term due to the following reasons. The cost for fuel and energy for transportation and heavy machinery movement will be cut down greatly with the use of lightweight blocks. Also the labour cost for construction will greatly reduce with lightweight blocks. Therefore although the initial cost for lightweight blocks is higher, it is much cheaper in the long run. In addition to this, a large amount of natural resources are saved with the use of EPS. In the current market, sand is expensive and becoming increasingly scarce to obtain. Aggregate too, although available now, will be scarce someday as the natural supplies are running out faster than they recharge. When considering these aspects, although a lightweight block will cost about LKR 94.00, it is a saving choice, in terms of money and time and also it is an environmentally friendly product.

CONCLUSION

Lightweight blocks are a serious and important necessity in civil engineering industry. Heavy blocks have several drawbacks such as causing wastages of time, over usage of fuel and energy consumption and cost incurred for construction and transportation. For this reason, having lighter blocks can increase speed of construction and efficiency of workers, overall reducing the cost as well. Blocks can be made lightweight in several ways; this research investigates the suitability of the use of EPS as a coarse aggregate in a non-load bearing block. EPS is most frequently used for the purpose of packaging fragile goods, and are thrown away after a single use. So with the use of EPS as an aggregate, a sustainable and useful product can be made.

With reference to past researches, an appropriate polymer was selected to replace the coarse aggregate in concrete. The chosen polymer was EPS; with its hydrophilic property, it was selected as the most suitable polymer to replace aggregate.

The initial mix was casted with reference to a past research that used EPS together with cement and sand. Since this mix was not suitable with terms of EPS distribution among grout, the water to cement ratio was varied till a suitable mix was found. Once the mix was stabilized, the water absorption test was conducted on the blocks with the suitable mix. The densities of all elements were measured.

Mixes 1, 2, 3 and 4 produced compressive strengths of 1.38, 0.17, 4.19 and 3.71 N/mm^2 respectively, at 28 days of age, while the control had a strength of 6.56 N/mm^2. Out of the compressive strengths of the mixes, Mix 3 produced the highest, while Mix 1, 3 and 4 produced values above the needed 1.2 N/mm^2. However, out of these mixes, only 4 had an appropriate distribution of EPS among grout. Mix 1 and 3 had clumps of grout in the EPS while Mix 2 had most of the grout in a layer at the bottom of each block. Mix 4 had a good distribution of EPS in the grout and also the fresh concrete was very easily to handle.

Once Mix 4 was casted, the water absorption test was carried out on the blocks of Mix 4. It produced a water absorption at 30 minutes of 0.143% which proved a good quality of concrete and the final water absorption of 0.67% which made the block suitable for non-load bearing purposes.

Finally, the cost analysis showed that the lightweight block was LKR 62.00 costlier than a conventional block. But this difference can be compensated with saved costs in labour, transportation and machinery use and fuel and energy consumption. Additionally, the block can save aggregate and sand, raw materials in large amounts, which leads to an environmentally friendly product.

These aspects show that a non-load bearing block may be made using constituents of cement, sand and EPS in the densities 550, 132, 13.5 kg/m^3 respectively, with a water to cement ratio of 0.40. It produces a compressive strength of 3.71 N/mm^2 at 28 days and a final water absorption of 12%. The blocks also floated on water which showed that the mix satisfied the density objective. These characteristics prove the Mix 4 cement blocks were suitable as lightweight non-load bearing concrete blocks.

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