Experimental Study On Behavior of Lightweight Concrete with Partial Replacement Of Coarse Aggregates With Expanded Polystyrene

J.N. Mwero[1], V.N. Onchaga[1]

1. Department of Civil & Construction Engineering, University of Nairobi.

Corresponding Author: johnmwero1@gmail.com

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Abstract

Developing countries especially those in Africa, such as Kenya, are facing the challenge of a growing middle class resulting in greater demand for housing facilities. Alternative and affordable building materials are being sought after. The usage of partial replacement of coarse aggregate using expanded polystyrene (EPS) beads in concrete to produce lightweight concrete gives prospective solution to the construction industry.Therefore, there is need to understand how the concrete replaced with EPS beads behaves and whether it meets the stipulated standards.

This paper assesses the suitability of using EPS beads as an alternative replacement material for coarse aggregates and its effect on: the compressive and tensile strength, water absorption rate, workability and density of the resulting concrete. The replacement of coarse aggregates by EPS beads was done in the ratios of 0%, 1%, 3% and 6% by weight.

The workability increases with the increase in the amount of EPS up with 6% replacement giving the highest slump value. Density reduced with the increase in the amount of EPS beads added to the mix with 6% having the lowest density of 1398kg/m^3 compared to a value of 2547kg/m^3 for the control sample. The water absorption rate increased with the increase in the amount of EPS with 6% replacement having a value of 4.18% compared to 1.40% for the control sample. The compressive strength reduced with increase in EPS but increased per each replacement as the curing period increased. The tensile splitting strength reduced with increase of EPS.

The usage of EPS beads as a potential partial replacement material for coarse aggregates was therefore found to be suitable for structural concrete at 15 replacement and masonry blocks for replacement percentage up to 3%.

Key Words: EPS, Density, Workability, Compressive strength, Tensile splitting strength, Water absorption.

1. Introduction

The demand for decent and affordable housing in Kenya, in line with the realization of the Sustainable Development Goals and Big Four Agenda, is increasing at an expedited rate due to the increase in population growth. This has resulted in increased infrastructural developments to meet the already existing deficit and meet the demands of population pressure. Demand for affordable construction materials is thus increasing day by day prompting the need for alternative building materials to reduce the cost of construction, and mitigate the rate of extraction and consumption of constituents of concrete.

Conventional concrete is made up of cement, aggregates, sand mixed with water. With the increased rates of population growth resulting in an increased rate in infrastructural development, there is also inflation for the need of these dry materials which results in increased quarrying and excavation activities. There, therefore, is the need to look for substitute sustainable supplementary materials to replace, either partially or fully, these materials to help in conserving of the environment.

EPS is a lightweight material, with a composition of 98% air and 2% polystyrene, which is manufactured from pre-expanded polystyrene beads being expanded using steam and then cooled. EPS flows when heated over 100^o Celsius and becomes hard again when cooled (Dow chemical company 2014). EPS beads are used for packaging of goods for easy handling and transportation. With the technological advancements, it is now used to form panels welded with reinforcement bars and shotcrete to form walls, slabs, partitions and stairs. Since, EPS is lightweight, non-biodegradable, hydrophobic and chemically inert in nature with good thermal and sound insulation, Fulton's Concrete Technology (1994) and Neville (1981), it can be used as a low-cost replacement of the coarse aggregates to produce light weight concrete and reduce the amount that ends up in landfills thus conserving the environment.

Light weight concrete is concrete of lighter weight than the conventional concrete. The density of light weight concrete typically ranges between 1440 and 1840 kg/m^3, where as these values vary between 2240 and 2400 kg/m^3 for normal weight concrete, (M. Uppiliyappani *et al* 2016). Using lightweight concrete has numerous advantages such as: lighter loads during consruction, reduced structural self-weight of the structure due to the reduced density which in turn reduces the section sizes of the members used: columns, beams and foundations and therefore results in reduced costs of construction and superior sound and thermal insulating properties. They can be incorporated in mortar or cement paste to produce low density concretes required for building applications like cladding panels and load-bearing concrete blocks and construction of floating marine structures, (K.Miled *et al*)

This paper therefore seeks to check the suitability of EPS beads as potential partial replacement material for coarse aggregates in production of lightweight concrete by testing the workability, compressive strength, tensile strength, water absorption rate and density of the sample specimen against a control sample.

2. Materials and Methods

The Expanded Polystyrene beads were obtained from National Housing Corporation (NHC) factory in Mlolongo.

Various replacements of coarse aggregates with EPS beads were done and the resulting concrete tested in its plastic and hardened state. In its plastic state, the workability was tested using the slump and compaction factor test while the mechanical properties of the hardened concrete tested after 7 and 28 days of curing.

The Mix Design

All mixes in this study were done in accordance with the merican Concrete Institute, ACI 211.2-98. The following mix was obtained and used for the various EPS replacements.

Table 1: Mix Proportions

Description	Coarse aggregates (kgs)		Fine aggregates (kgs)	Cement (kg)	Water (kg)	EPS beads (g)
	14-20mm	6-10mm				
Control mix	18.75	13.75	15	10.25	4.5	0
1% EPS	18.75	13.6	15	10.25	4.5	137.5
3% EPS	18.75	13.3	15	10.25	4.5	412.5
6% EPS	18.75	12.9	15	10.25	4.5	825

Slump Test
The slump test was done in accordance with BS 1881: Part 102: 1983.

Compaction Factor Test
The compaction factor test was done in accordance with BS 1881: Part 103:1993.

Compressive test
Compressive strength was done in accordance with BS1881-116:1983 on cubes measuring 150mm by 150mm by 150mm after 7 and 28 days of curing.

Tensile strength of concrete (Cylinder splitting)
The tensile splitting strength test was done in line with the specifications of BS 1881-117:1983. The concrete cylinders were tested after 28 days of curing.

Water Absorption Test
For this test, 150mm X 150mm X 150mm cubes were cast and cured for 28 days. The cubes were then removed from the curing tank, left to drain the excess surface water and weighed and this notedc as the dry weight. The cubes were then immersed in water for 24 hours. Cubes were removed, patted dry with a cloth and weighed for the wet weight. Water absorption is expressed as the percentage increase in weight as shown below;

Percent Water Absorption = $\frac{wet\ weight - dry\ weight}{dry\ weight} x\ 100$

Density Test
The density of the hardened concrete specimen was done in accordance with BS 1881: Part 114:1983.

3. Results and Discussion

Properties of plastic concrete

Fresh Concrete Mixes

During the compaction of the concrete mixes containing EPS beads, segregation and bleeding was observed. EPS being a lighter material, density of 6.86kg/m^3, as compared to the constituents rose to the surface of the mix as vibration prolonged. This was minimised by use of a tamping rod prior to placing the cubes on the vibration machine to reduce the time of vibration.

Slump test results

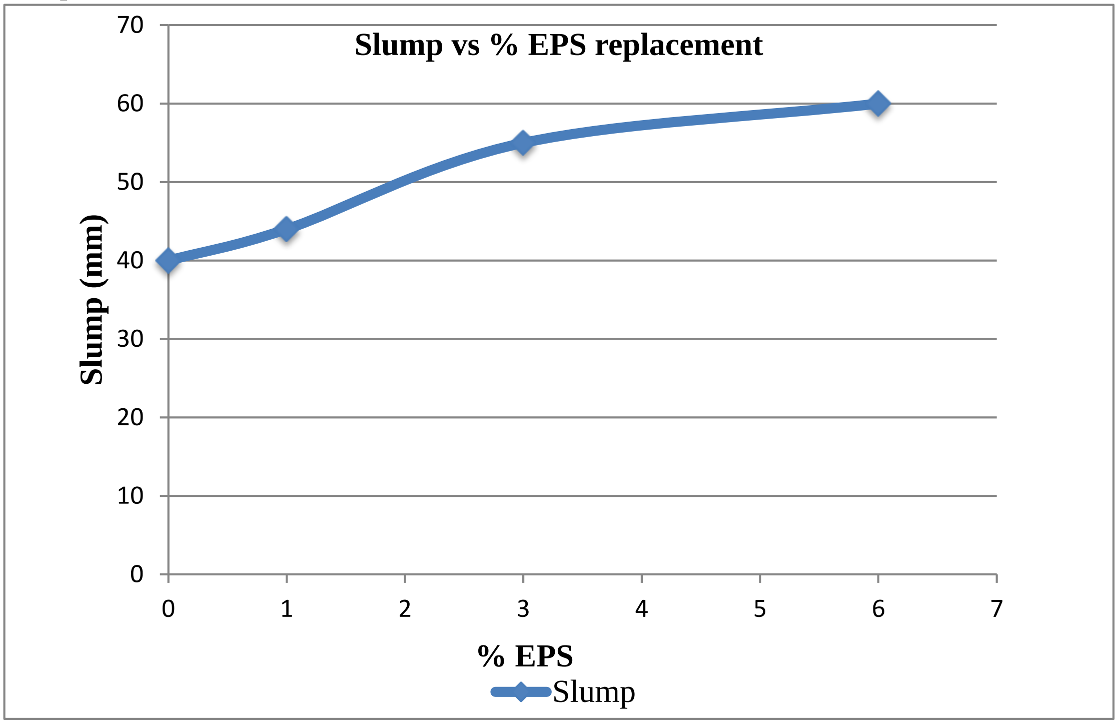


Figure 1: Slump vs % EPS replacement

From the Figure 1 above, the slump increased with an increase in the percentage of EPS introduced into the mix with the 6% replacement having the highest slump. From these observations, it implies that workability of concrete mix increased on addition of polystyrene. This can be attributed to the smooth and round surface of the EPS beads which in turn acted as ball bearings making it easier for them to move around in the mix easily. The increase in workability however does not mean increase in strength as the EPS has low specific gravity as compared to coarse aggregates but it implies that the mix is easy to place.

Compaction factor results

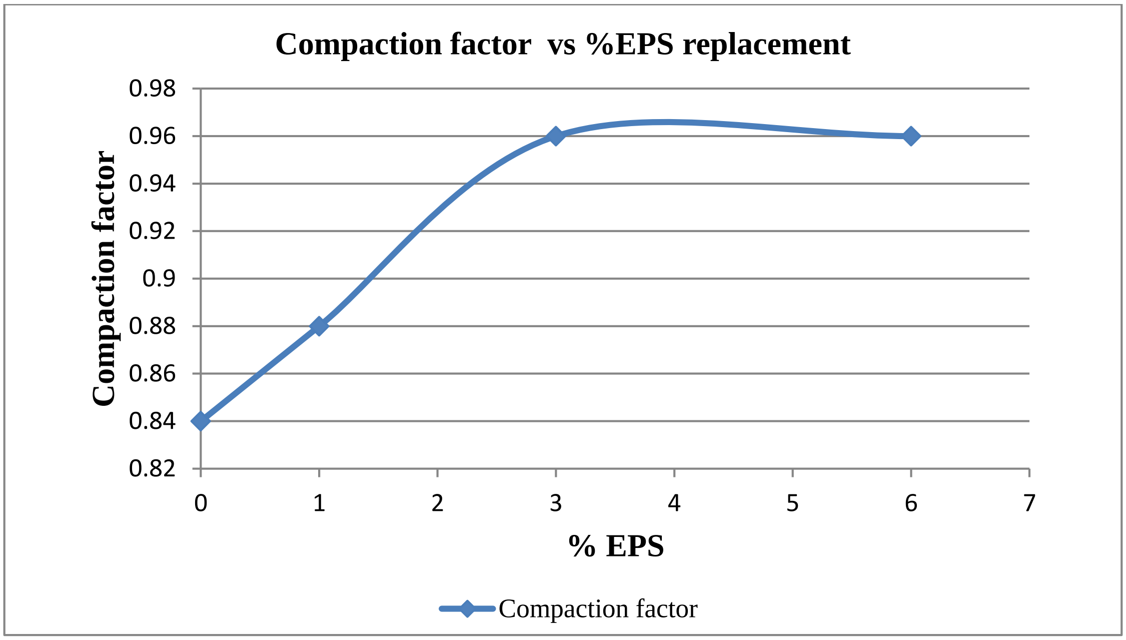


Figure 2: Compaction factor against %EPS

Workability of concrete is important in achieving maximum compaction. The higher the workability which is signified by higher slump values, the higher the compaction and thus maximum density. From Figure 2 above, it was observed that the compaction factor increased with each increase in percentage EPS beads until 3% replacement. After 3%, additional EPS beads had no impact on the compaction factor as the mix had already attained maximum compaction. With the increased percentages of EPS added to the mix, there was observed to have increased workability and thus as the percentages increased so did the compaction factor. Compaction factors tending towards 1 imply that the concrete is tending towards self compaction and that there is elimination of voids from the mix thus high densities and strengths. The increase in compaction factors with increase in EPS reiterates the fact that there is increased workability.

Properties of hardened concrete

Compressive strength test results

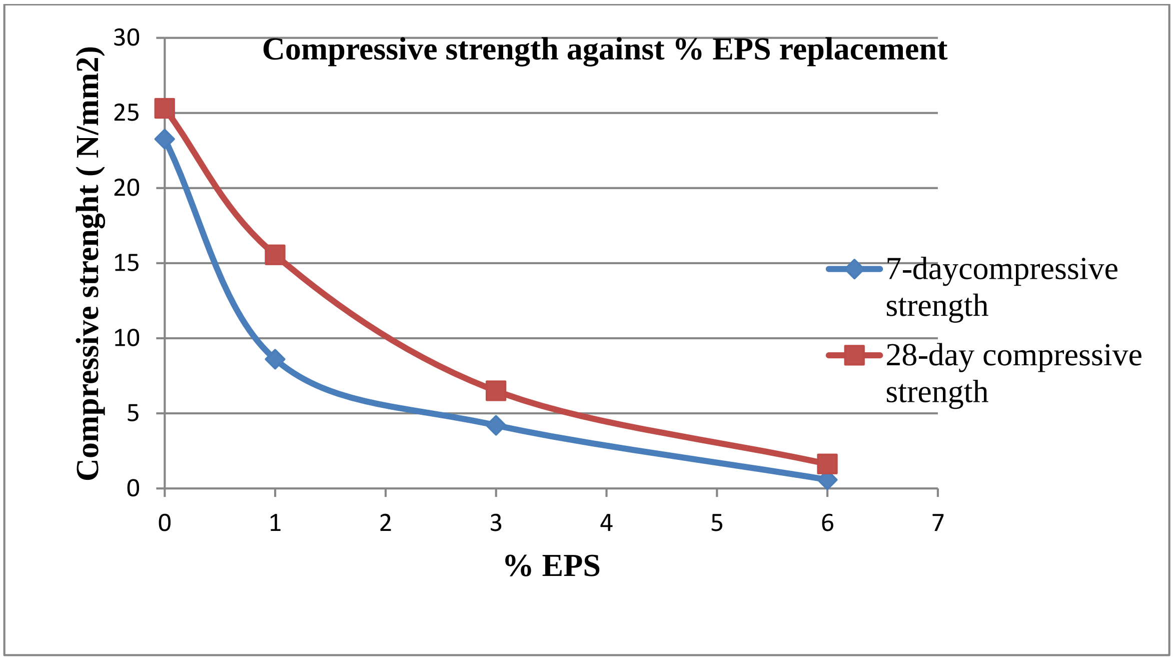


Figure 3: Strength against %EPS

From Figure 3, the strength is seen to be reducing with the increase in the percentage of EPS in both the 7 day and 28-day specimen. This is attributed to the fact that EPS beads have a low specific gravity (0.011) as compared to that of coarse aggregates (2.49) they are partially replacing thus reducing the strength. Increase in the amount of the beads also increased the voids in the mix due to their rounded surfaces which as compared to coarse aggregates are angular and thus offer more interlocking. The reduced interlocking reduced the strength.

There is also increased strength between the 7-day and 28-day specimen. This is due to the increased curing period and thus more time for the hydration process to take place and result in more Calcium Silicate Hydrate (CSH) gel being formed thus increasing the bond between the aggregates which in turn results in increased strength. At 7 day, it is estimated that the specimen will have achieved approximately 65% of the design strength.

The strength, as shown in Figure 3, above reduced by 38.34%, 74.3% and 93.56% for the partial replacement of 1%, 3% and 6% respectively for the 28-day strength test compared to the control specimen.

It was noted that upon loading of the specimens partially replaced with EPS, they underwent reduction in height and had a compressibility attribute to them as opposed to the control sample which cracked and spalled suddenly upon reaching the failure load. This is because the EPS beads are 98% air and thus, they result in compressibility of the concrete. The different variations in compressive strength imply that the concrete can be used to make special concrete blocks such as sound and thermal insulation blocks for percentages resulting in compressive strength above 5N/mm^2 according to BS 5628: Part 1:1992.

Failure Modes

As an axial load was applied to a specimen containing EPS beads, the observed failure was gradual as compared to the quasi-brittle failure of the control sample. For the control sample, visible cracks were observed as the sample continued to be loaded leading to failure point. For the EPScrete, the cracks observed were less wide and finer as shown in Plate 2. With continued loading, the sample was seen to bulge out and reduce in height as shown by Plate 1 and Plate 4 respectively, due to the compressible nature of the EPS caused by expulsion of air from the beads and due to its low elastic modulus. This implies that increased loading of EPScrete for long durations would result in huge and permanent deformations of members; plastic deformation and thus aesthetically unappealing. The deformations increased with increase in percentage of EPS with 6% having the highest strain.

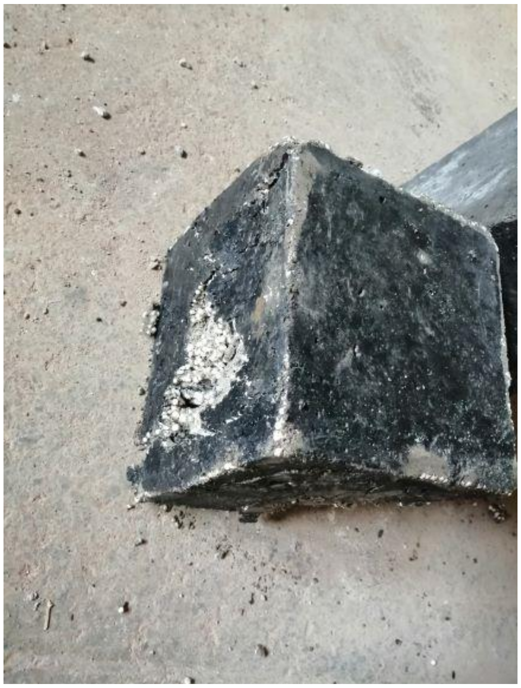


Plate 1: Bulging of EPScrete upon loading

Plate 2: Fine cracks indicating failure

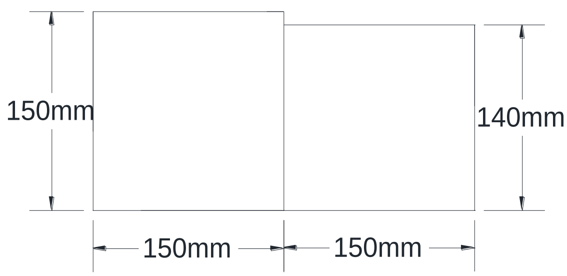
Plate 3: Split cylinder

Plate 4: Height difference between control and EPScrete specimen

Plastic Deformation

As observed from Plate 4 above, there is shrinkage that occurred in the EPScrete thus the height difference. This is because EPScrete undergoes plastic deformation as compared to conventional concrete's quasi-brittle failure. The presence of EPS in the mix implies presence of voids filled with air, due to their poor interlocking capacity. EPS beads being 98% air makes it have a high degree of compressibility and low elastic modulus. As loading continued, the air was expelled from the mix resulting in height and therefore volume changes. Under prolonged loading, EPScrete will undergo huge and visible deflections as opposed to conventional concrete as evidenced by the strain of the 6% replacement EPScrete at 0.067 as compared to the ultimate strain of concrete of 0.0035.

$$strain\ of\ EPScrete = \frac{10}{150} = 0.067$$



Split tensile strength test

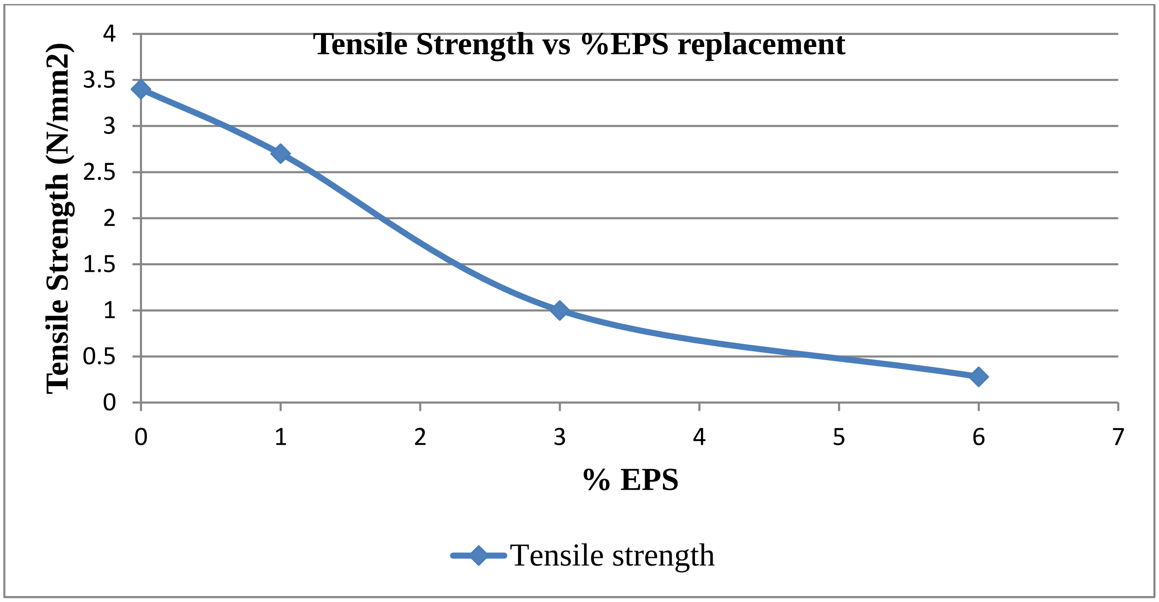


Figure 4: Tensile graph

The tensile strength as observed reduced with increase in the percentage of EPS beads. The reduction was in the order of 20.5%, 70.6% and 91.9% for the partial replacement of 1%, 3% and 6% respectively compared to the control mix. The reduction in tensile strength is due to the reduction in stress area and in density due to the introduction of EPS beads results in reduction in tensile strength. The EPS have a rounded smooth surface thus less surface area to volume ratio leading to reduced bonding between the aggregates and the cement paste thus resulting in lower bonding strength. The control specimen as observed has the hughest flexural strength due to the angular and rough nature of the aggregates thus more interlocking and more strength. Aggregates occupy 60-75% of the concrete mix and the strength of aggregates has a direct impact on the strength of the resulting concrete, Ezeldin & Aiten (1991). Increase in coarse aggregate content results in increase in strength due to the reduction in voids, Ruiz (1966). This type of concrete can therefore be used for wall partitions and cladding.

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Density Results

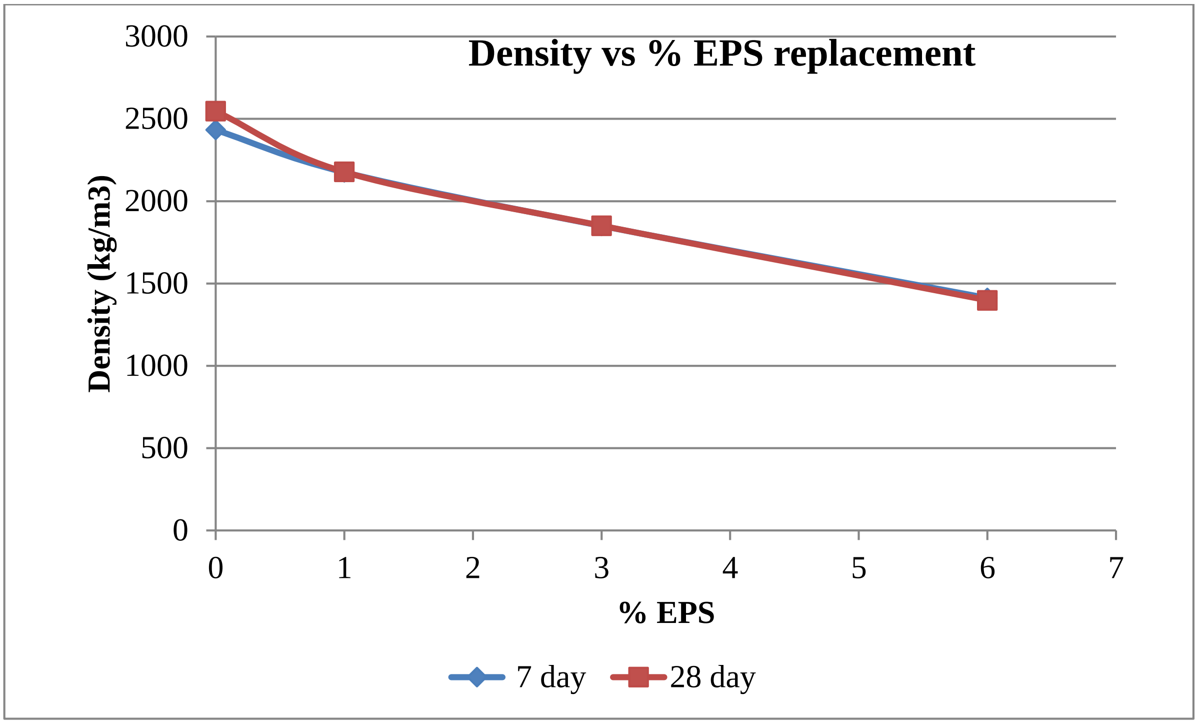

Figure 5: Density graph

As observed from Figure 5 above, there is a decrease in the density of the concrete with increase in percentage of EPS beads in the mix. This is because of the low specific gravity of the EPS beads, as compared to that of the coarse aggregates. As compared to the control mix, the voids introduced with the increase in the percentage of EPS are high which also reduces the density of the concrete. There are similarities in the densities obtained between the 7 day and 28 day density results due to that fact that the same batched concrete was used to cast the cubes for both the 7-day and 28-day specimen. The discrepancies and inconsistencies observed in the density values obtained 7 and 28 days are due to errors in mixing and compaction.

Water Absorption test results

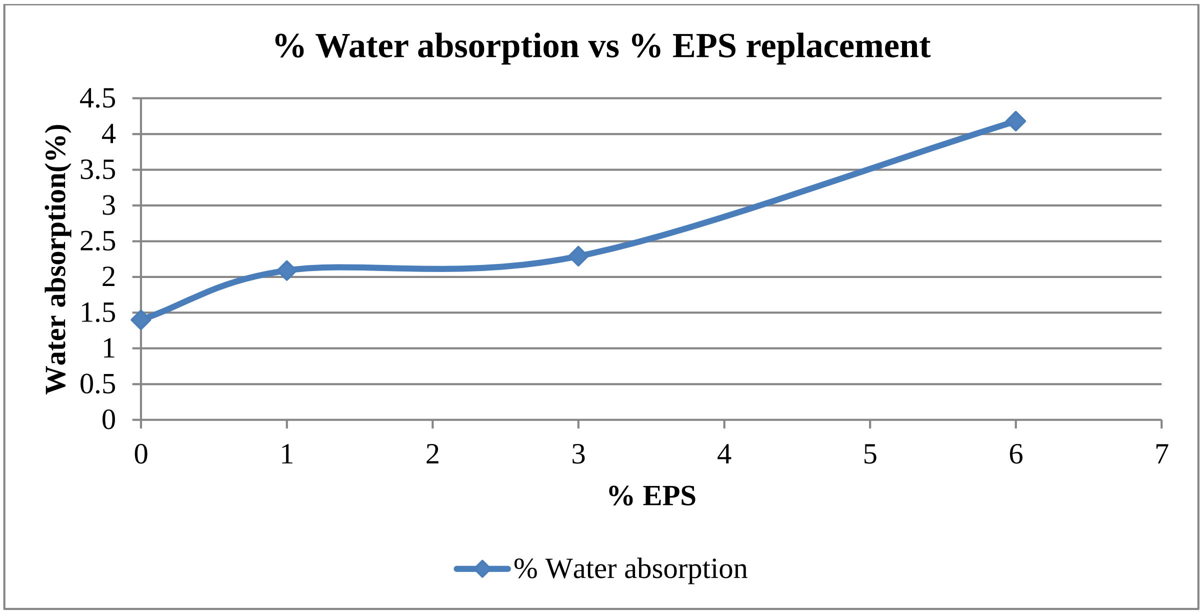

Figure 6: Water absorption graph

From Figure 6 above, the water absorption is observed to increase with an increase in the percentage of EPS beads introduced. The control mix has the least water absorption while 6% replacement has the highest. This is attributed to the increased porosity as the volume of EPS beads increases. Increase in EPS beads results in increase in voids in the mix which causes the reduction in density. The rounde shape of the EPS beads result in poor packing capacity of the concrete thus increased number of pores in the resulting concrete. This type of concrete can be used for lining drainage structures due to high porosity nature and help in controlling of stormwater thus mitigating flooding.

4. Conclusion

The objectives of the research project were achieved and these conclusions can be drawn from the tests carried out;

The partial replacement of coarse aggregates with EPS beads resulted in:

- Increased in workability with increase in the volume of EPS beads as the slump increased with each percentage increase,
- The compaction factor increased with increase in EPS volume thus reiterating that there is increased workability with increase in volume,
- Decreased density with increase in volume of EPS due to the low specific gravity of EPS,
- Density decrease implies reduced dead loads thus cost-effective construction,
- Strength decreases with the increase in workability of the concrete; increase in the volume of EPS in the mix,
- The EPScrete thus can be used for both structural and non-structural applicationse.g. wall panels, wall partitions etc. and thus the disposal of the EPS beads is handled,
- Suitability of EPS beads being used for load bearing structures, for 1% replacement, ($16N/mm^2$) and special and non-load bearing blocks for 3% and 6% replacement, ($7N/mm^2$ and $2N/mm^2$) respectively.

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5. Recommendations

- The resulting concrete is suitable for use in the production of lightweight concrete blocks with a strength range of $2N/mm^2$ to $16N/mm^2$, which can be used for non-structural construction of low rise residential buildings, special blocks and non load-bearing structures such as wall partitions and as cladding.
- Due to the high porosity of the concrete, it can be used in production of porous concrete for use in lining of drainage structures to control stormwater and runoff.
- The resulting concrete has a high degree of workability and flowability with increase in EPS content, therefore it can be used in production of self compacting lightweight concrete.

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