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Development of Lightweight High-Performance Concrete with Fly Ash and EPS Beads as Sustainable Partial Replacements

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ABSTRACT

In modern construction, concrete remains the fundamental building material, used across a diverse range of structures from residential buildings to high-rise skyscrapers. Traditionally, concrete consists of cement, fine aggregates, coarse aggregates, water, and admixtures, with variations depending on specific requirements. However, the excessive extraction of natural sand from riverbeds has led to severe environmental issues, including riverbank erosion, loss of aquatic habitats, and disruptions in water flow, making sand an increasingly scarce and expensive resource. Additionally, cement production is a major contributor to CO_2 emissions, exacerbating global climate change. In response to these challenges, this study explores the sustainable alternative of partially replacing cement with fly ash and fine aggregate with expanded polystyrene (EPS) beads to develop an eco-friendly lightweight concrete.

The experimental investigation focuses on M25 grade concrete, with cement replaced by fly ash at 25% and 35%, while fine aggregates are replaced with EPS beads at 0.4%, 0.6%, and 0.8%. Fly ash, a pozzolanic industrial byproduct, enhances durability, workability, and sustainability, whereas EPS beads, being lightweight and thermally insulating, contribute to reducing the overall density of concrete. Compressive strength tests were conducted to evaluate the mechanical performance of the modified concrete mixes.

The results indicate that the optimal mix is achieved with 25% fly ash and 0.6% EPS beads, yielding a compressive strength increase from 28.4 N/mm² to 35.6 N/mm², demonstrating a significant improvement over conventional concrete. Similarly, at 35% fly ash replacement with 0.6% EPS beads, the compressive strength increased to 34.1 N/mm², showing a promising enhancement. The incorporation of EPS beads reduces self-weight, making this concrete an ideal candidate for high-rise buildings, precast elements, and non-load-bearing structures, where weight reduction is crucial without compromising strength.

This study confirms that fly ash and EPS beads can effectively replace cement and fine aggregate, offering both economic and environmental benefits. The reduction in cement usage leads to a lower carbon footprint, while the utilization of EPS waste promotes sustainable waste management. The proposed lightweight concrete enhances energy efficiency in buildings due to its thermal insulation properties, making it suitable for green construction projects. Further

research may focus on long-term durability, impact resistance, and optimization of mix proportions for large-scale applications.
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Keywords: EPS beads, fly ash, M25, Lightweight Concrete, EPS Beads, Fine Aggregate Replacement.

1. INTRODUCTION

Light weight concrete is an important and versatile material in modern construction. It has many advantages of dead load reduction, high thermal insulation; increase the process of building and lowers haulage and handling cost. It also lowers power consumption for extreme climate condition due to possessing property of low thermal conductivity. Nowadays lightweight concrete is commonly used in precast and prestressed components. Light weight concrete offers design flexibility and substantial cost savings by providing less dead load, improves seismic structural response, better fire rating, decreased storey height, smaller size structural members, lower foundation cost, and less reinforcing steel. The concrete made with light weight concrete exhibit lower thermal conductivity than of normal weight concrete. Therefore, light weight concrete provides more efficient fire protection than dense aggregates as it is less liable to spalling and has a higher thermal insulation. The LWC has been widely across other countries such as USA, UK and Sweden. Light weight concrete plays an important role in structural engineering and its use is steadily increasing. It is defined as a type of concrete which includes an expanding agent in that it increases the volume of mixture. It is lighter than conventional concrete with dry density of 300kg/m^3 up to 1840 kg/m^3. The reduction in weight by use of light weight concrete will be advantageous, especially for building structures.
Lightweight aggregate can be naturally occurring but they are relatively scarce. Most of the lightweight aggregate material that is used for lightweight concrete manufactured by some means. For example, thermal treatment or pre-processing of certain naturally occurring minerals can produce an aggregate having a cellular or foam-like structure, hence a lower bulk specific gravity. Blast furnace is an example of a lightweight aggregate. Fly ash can used in pervious concrete a substitute for portion of the cement. The advantage of using fly ash is obvious. Fly ash is a by-product of coal burning in power plant, its utilization saves the energy required to product the cement.

2. LITERATURE SURVEY

Abdullah Anwar *et al*., (2014) studied the Compressive Strength of Concrete by Partial Replacement of Cement with High Volume Fly Ash and presented a brief review with mixtures containing 10%, 20%, 30% and 40% Fly Ash by the bulk of the cementitious material (OPC) for M30 and M40 grade of concrete. The test result indicates that the compressive strength of mix with 10%, 20% and 30% replaced with fly ash were more as compared with conventional concrete thus enhancing the durability of structures. When the percentage of replacement is increased the water/ binder ratio gets reduced, thereby, increasing the compressive strength. Also, it is observed that the compressive strength of concrete having more than 40% replacement of cement by fly ash suffers adverse effects though water binder ratio is gradually lost weight. The compressive strength of the concrete mix with 40% replacement with fly ash was lesser than the conventional concrete at 28 days. The result obtained for 28 days compressive strength confirms that the optimal percentage for replacement of cement with fly ash is about 30%. Yet, in reality approximately 50% of the Fly Ash produced throughout the world is stockpiled land filled as a wasteland.

Vandale Amar Diliprao, et al(2019) deals with the study of polystyrene foam are thermoplastic material obtain by Polymerization of styrene. In construction has lot of advantages by using of expanded polystyrene as compare use of conventional material which result in sustainable future. EPS is versatile durable material that offers excellent insulation property. As the structure of consist of 98% air its initial thermal properties are maintain throw out it's working life. It can be manufacture in a wide range of shape & sizes. The use expanded polystyrene in construction has lot of advantage compare with use of conventional material which result in sustainable future. EPS is use as lightweight aggregate to produced light weight concrete with unit weight less than 1000kg/m3 which make it as lightweight concrete coarse aggregate is measure contributor for heavy weight of concrete as replacing it with EPS beads result reduction of the density of concrete.

Nagaswaram Roopa et. al 2017, they concluded that the workability of concrete in terms of slump cone and compaction factor shows that Compaction factor changes slightly with increasing fly ash, Thermocol replacement and the slump cone also changes with the % increase in the replacement of fly ash, Thermocol content and the values falls within the value for normal range of concrete. By conducting the compressive strength of concrete cubes compressive strength is increased by partial replacement of cement with fly ash and fine aggregate with Thermocol. For 3 days of curing period ,it is observed that the strength of concrete at partial replacement of fly ash and Thermocol is increased when compared to the normal compressive strength of concrete. For 7 days of curing period ,it is observed that the strength of concrete at partial replacement of fly ash and Thermocol is increased when Compared to thermocol compressive strength of concrete. For 28 days of curing period , it is observed that the strength of Concrete at partial replacement of fly ash and Thermocol is increased compared to normal cubes. It is for the proportion of 35%fly ash and 0.2% Thermocol. In the same manner the compressive strength of concrete is increased Compared to the normal mix and partial replacement of 35% fly ash and0.2% Thermocol.

Dr. G. Elangovan 2015, he concludes that Based on the test results obtained from the experimental programme of this work, the following major conclusions are arrived from workability, compressive strength test, durability test and cost analysis. From the workability test results, slump cone value increases for concrete mix containing fly ash and thermocol when compared with reference concrete mix (R). From the experimental test results, the compressive strength of concrete mix after 7 days curing having 60% fly ash and 0.3% thermocol (FT3) has the highest strength of 23.55 N/mm2 , and its percentage improvement is 47.28 N/mm2 over reference mix. From the test results, the compressive strength of concrete mix after 28days curing having 60% fly ash and 0.3% thermocol 60% fly ash replacing with cement has the highest compressive strength of 25.62 N/mm^2 and its percentage improvement is 22.70 N/mm^{2} over reference mix. Consequently, it is concluded that concrete mix having 60% fly ash and 0.3 % thermocol 60% fly ash replacing with cement is better mix and has the highest compressive strength for both 7 days and 28 days test result. By analyzing its cost and strength parameters, concrete mix having 60% fly ash replacing with cement is comparatively more economical.

3. PROPOSED SYSTEM

3.1 Aim

The aim of study is to evaluate the performance and suitability of replacement of EPS beads with fine aggregate and cement with fly-ash in concrete manufacturing.

3.2 Objective

The objectives of experimental study are:

- Study on strength characteristics of M25 grade concrete with replacement of 25%, 35% cement by fly-ash and replacement of 0.4%, 0.6%, 0.8% fine aggregate by EPS beads.
- To determine the workability by slump cone test & compaction factor test.
- To determine the compressive strength for 7, 14, 28days curing.
- To determine the split tensile strength for 28days curing

3.3 Methodology

1. Collect the fly-ash (class F) and waste thermacoal or EPS beads.
2. If EPS beads are not passed from IS Sieve 4.75mm, then split into small pieces by manual method of splitting.
3. Choose the mix design and literature survey (for mix proportions and pending works from past researches).
4. Design mix design of M25 grade concrete.
5. Find out the mix proportions for different mix grades, those are mentioned below table 3.1.
6. Mixing of all dry materials for 2mintues and required quantity of water to add the dry mixed materials and mix it for 3-5mints.
7. Freshly prepared concrete test with slump cone test.
8. Cast the cube & cylinders moulds based on the requirement, those are mentioned below table 3.2.
9. Cure the sample in water for 7,14,28 days for cubes & 28days for Cylinders.
10. After curing ages, the samples tested. Compressive strength test for cubes and split tensile strength test for cylinders.
11. Results & discussions
12. Conclusions

Table 3.1 Mix Proportion grades and details

MIX	Fly ash% – EPS Beads%
M0	0-0
M1	25 – 0.4
M2	25 – 0.6
M3	25 – 0.8
M4	35 – 0.4
M5	35 – 0.6
M6	35 – 0.8

Table 3.2: Experimental Program

Type of test to be conducted	Behaviour to be identified	Specimen	Size	No
Slump cone test	Fresh concrete properties	-	-	
Compression test	Compressive strength	Cube	150 X 150 X 150 mm	63
Tensile test	Split tensile strength	Cylinder	300 X 100 mm	21
Water absorption	Water absorption	Cube	150 X 150 X 150	21

test			mm	

4. RESULTS AND DISCUSSIONS

The results of the experimental investigation for the various tests are discussed in this chapter.

4.1 Fresh properties of concrete (Slump cone test)

The slump Values of the concrete for replacement of sand with EPS beads by 0, 0.4, 0.6, 0.8% and cement with fly ash 25, 35% are shown in below table and graph.

Table 4.1: Slump Values (mm) for different mixes

MIX	FLYASH% – EPS %	Slump (mm)
M0	0-0	120
M1	25 – 0.4	124
M2	25 – 0.6	127
M3	25 – 0.8	132
M4	35 – 0.4	134
M5	35 – 0.6	140
M6	35 – 0.8	142

It is observed that there is increase in the workability of the concrete the sand replacing with EPS beads and cement replacing with fly ash. Based on the observations, all of the slump values are in the medium workability range.

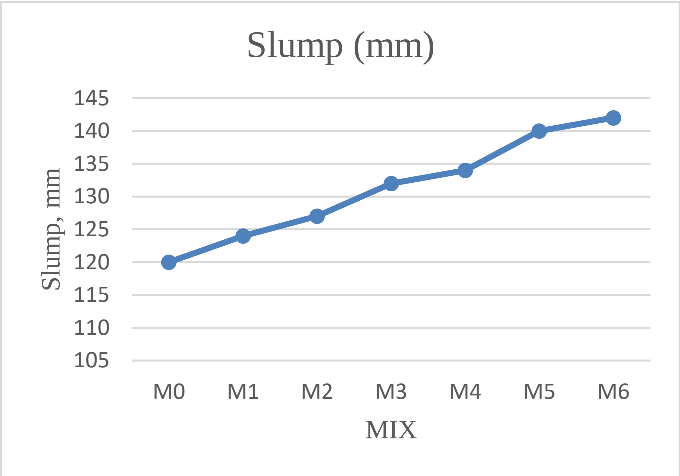

Fig 4.1 Slump Values Vs % MIX

4.2 Compressive strength test

The compressive strength values of the concrete for replacement of fine aggregate with EPS beads by 0, 0.4, 0.6, 0.8% and cement with fly ash 25, 35% are shown in below table and graph.

It is observed that there is increase in the compressive strength of the concrete when the fine aggregate with EPS beads by 0, 0.4, 0.6, 0.8% and cement with fly ash 25, 35%. The percentage increase of compressive strength (28days) values for M1, M2, M3, M4, M5, M6 replacement of

Fine aggregate with EPS beads – cement with fly ash are 7.04%, 25.35%, 10.56%, 5.28%, 20.07%, 0.7% respectively. Based on the observations, all of the compressive strength values are higher for EPS & Fly ash replacement in the concrete. The optimum dosage of Fly ash replacement in cement and EPS beads replacement in natural fine aggregates is 25% & 0.6% (M2 mix).

Table 4.2: Compressive strength (Mpa) for different mixes

MIX	FLYASH% – EPS %	7days	14 days	28 days
M0	0-0	17.04	25.561	28.4
M1	25 – 0.4	18.24	27.36	30.4
M2	25 – 0.6	21.36	32.04	35.6
M3	25 – 0.8	18.84	28.26	31.4
M4	35 – 0.4	16.87	25.9	29.9
M5	35 – 0.6	19.65	29.67	34.1
M6	35 – 0.8	16.6	24.7	28.6

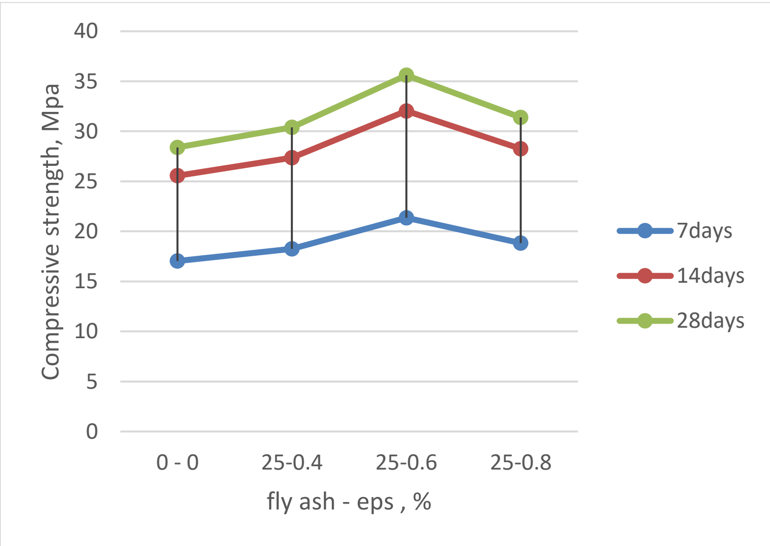

Fig 4.2(a) Compressive strength Vs % (fly ash – EPS %)

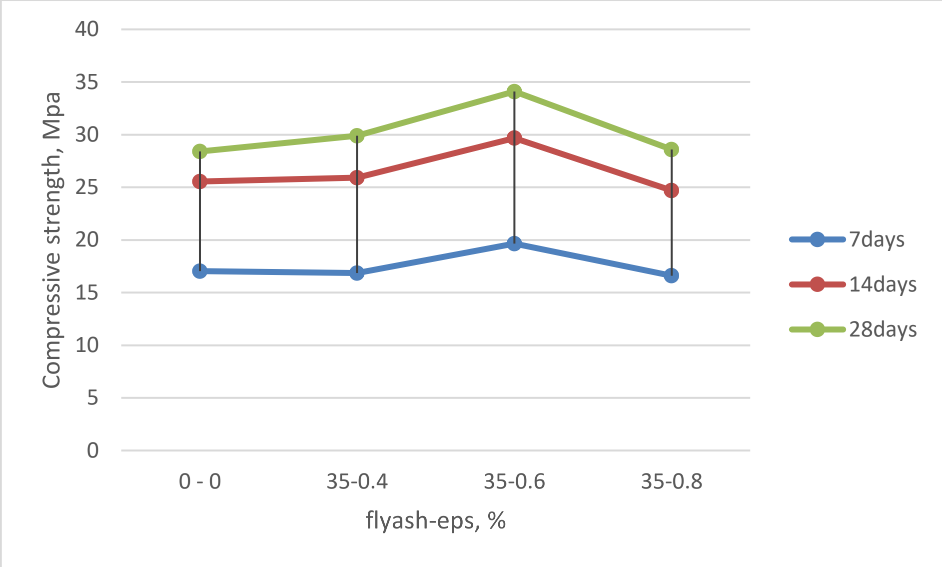

Fig 4.2(b) Compressive strength Vs % (fly ash – EPS %)

4.3 Split tensile strength test

The Split strength values of the concrete for replacement of fine aggregate with EPS beads by 0, 0.4, 0.6, 0.8% and cement with fly ash 25, 35% are shown in below table and graph. It is observed that there is increase in the tensile strength of the concrete when the fine aggregate with EPS beads by 0, 0.4, 0.6, 0.8% and cement with fly ash 25, 35%. The percentage increase of tensile strength (28days) values for M1, M2, M3, M4, M5, M6 replacement of Fine aggregate with EPS beads – cement with fly ash are 7.1%, 26.76%, 8.27%, 4.75%, 18.83%, 0.058% respectively. Based on the observations, all of the tensile strength values are higher for EPS & Fly ash replacement in the concrete. The optimum dosage of Fly ash replacement in cement and EPS beads replacement in natural fine aggregates is 25% & 0.6% (M2 mix).

Table 4.3: Split tensile strength (Mpa) for different mixes

MIX	FLYASH% – EPS %	28 days
M0	0-0	3.408
M1	25 – 0.4	3.65
M2	25 – 0.6	4.32
M3	25 – 0.8	3.69
M4	35 – 0.4	3.57
M5	35 – 0.6	4.05
M6	35 – 0.8	3.41

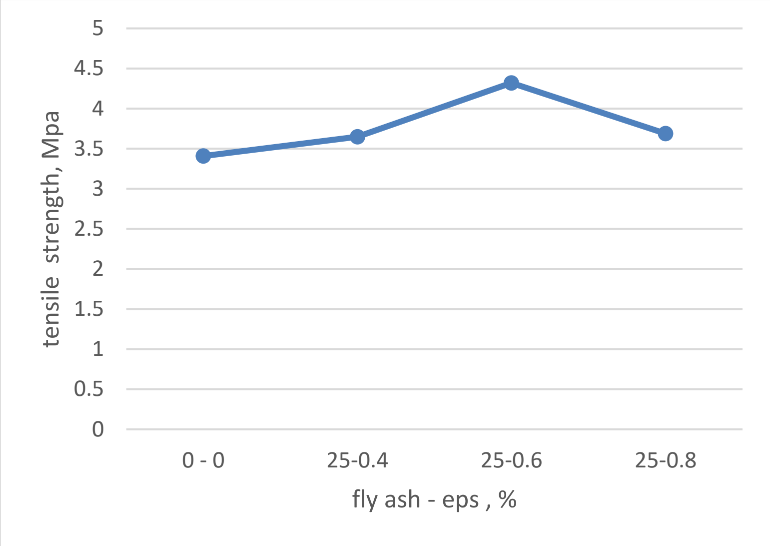

Fig 4.3(a) Tensile strength Vs % (fly ash – EPS %)

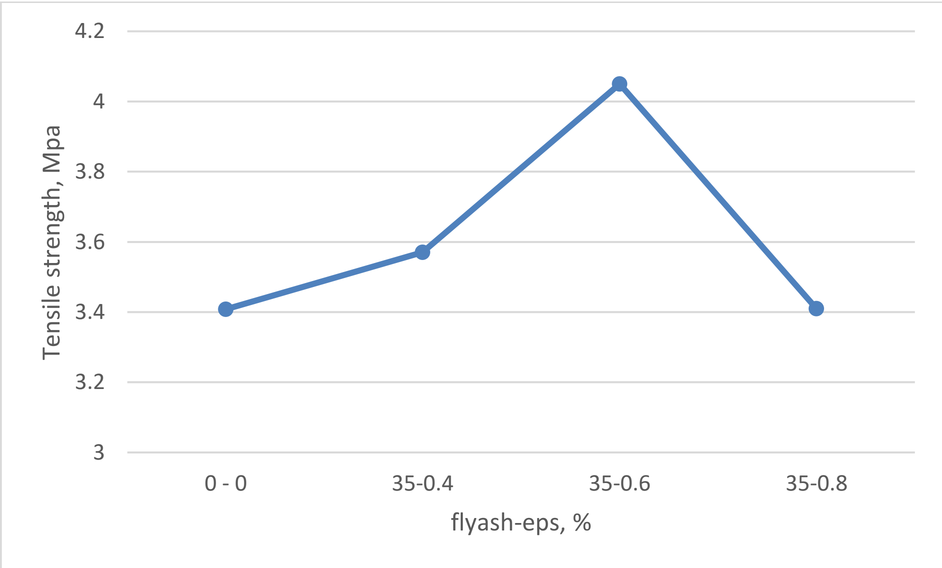

Fig 4.3(b) Tensile strength Vs % (fly ash – EPS %)

4.4 Water absorption test

The water absorption values of the concrete for replacement of fine aggregate with EPS beads by 0, 0.4, 0.6, 0.8% and cement with fly ash 25, 35% are shown in below table and graph.

It is observed that there is increase in the water absorption of the concrete when the fine aggregate with EPS beads by 0, 0.4, 0.6, 0.8% and cement with fly ash 25, 35%. The percentage decrease of water absorption values for M1, M2, M3, M4, M5, M6 mixes replacement of Fine aggregate with EPS beads – cement with fly ash are 23%, 28.2%, 35.89%, 48.7%, 53.84%, 56.4% respectively. Based on the observations, all of the water absorption values are lesser for EPS & Fly ash replacement in the concrete. The least water absorption of Fly ash replacement in cement and EPS beads replacement in natural fine aggregates is 35% & 0.8% (M6 mix).

Table 4.4: water absorption (%) for different mixes

MIX	FLYASH% – EPS %	Water absorption

		(%)
M0	0-0	3.9
M1	25 – 0.4	3.0
M2	25 – 0.6	2.8
M3	25 – 0.8	2.5
M4	35 – 0.4	2.0
M5	35 – 0.6	1.8
M6	35 – 0.8	1.7

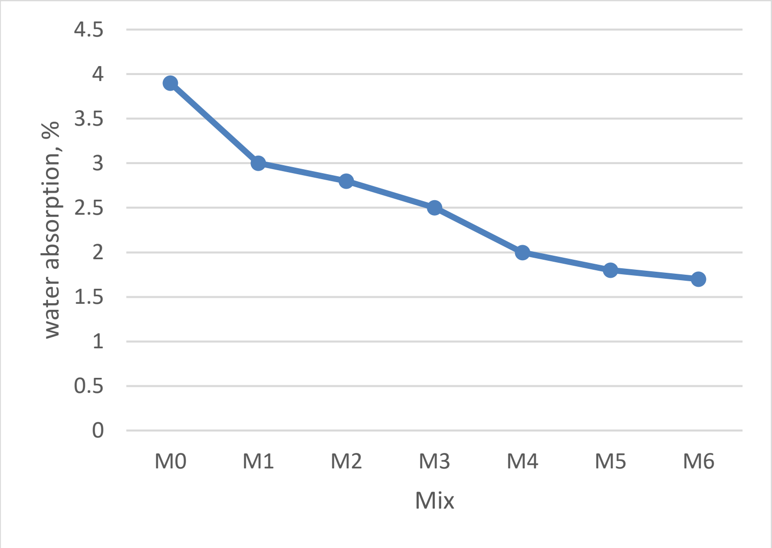

Fig 4.4 Water absorption Vs % Mix

5. CONCLUSIONS

As we have conducted different types of tests on lightweight concrete we found various results. By conducting compressive and split tensile strength test on concrete cubes and cylinders, we found that compressive, tensile strength is slightly improved by partially replacing the cement with fly ash and combine aggregate with Eps beads. In this whole process we are trying to increase the strength of concrete and for that we are using mix aggregate cement of fly ash. The workability increases with increasing fly ash and eps replacement in concrete. The eps beads was light weight and specific gravity was less than 1%, it occupies the more spaces and finally it's light weight. This also called light weight concrete. The cement replacing 25% with fly ash and fine aggregate with eps beads with 0.6% given the higher compressive and split tensile strength compare to the all-other mixes including control mix (0% replacement). The percentage increment of compressive and tensile strength are 25.35% and 26.76%. The cement replacing 25, 35% with fly ash and fine aggregate with eps beads with 0.4, 0.6, 0.8 % given that, increasing replacement the water absorption value decreases. The least water absorption value for compressive and split tensile strength compare to the all-other mixes including control mix (0% replacement). The percentage increment of compressive and tensile strength are 25.35% and 26.76%. The cement replacing 25, 35% with fly ash and fine aggregate with eps beads with 0.4, 0.6, 0.8 % given that, increasing replacement the water absorption value decreases. The least water absorption value for 35% replacement cement with flyash and 0.8% replacement fine aggregate with EPS beads.

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