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EFFECTS OF EXPANDED POLYSTYRENE BEADS ON THE STRENGTH PROPERTIES OF BRICK AGGREGATE CONCRETE

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Graphical abstract

Abstract

Bangladesh's construction industry has grown significantly over the past two decades. The construction industry is progressing at a faster speed, which has raised the raw demand for building materials. Finding an alternative to natural aggregate in concrete casting as a partial replacement is a smart concept to protect natural resources. Our environment is severely harmed by the production of bricks. On the other hand, polystyrene, a common plastic packaging material, degrades to harm the environment and produces useless plastic waste. To conserve natural resources, it can be a good idea to use plastic trash as a partial replacement for natural aggregate in concrete casting. The addition of EPS to concrete offers a variety of benefits. These include reduced self-weight in structures, lighter weights during construction, and higher thermal resistance. In this experiment on the characteristics of concrete structure, expanded polystyrene beads have been used in place of coarse aggregate in this experiment. In various combinations (1:1:2), (1:1.5:3), and (1:2:4), EPS beads replace 0%, 10%, 20%, and 30% of the volume of the course aggregate portion. The compressive strength, unit weight and splitting tensile strength of these mixes are all measured for the complete testing procedure. The optimal levels of compressive strength, splitting tensile strength, and unit weight of 12.65 MPa, 1.89 MPa, and 46.28 kg/m^3 respectively, and the normal concrete's compressive strength, splitting tensile strength, and unit weight of about 19.16 MPa, 2.05 MPa, and 12.24 kg/m^3 are successfully developed in Grade M25 EPS-based concrete with a replacement percentage of 10%. The results indicate that EPS beads have the potential to produce lightweight concrete with a moderate strength grade that might be used in a wide range of applications.

Keywords: *Aggregate, EPS beads, Compressive strength, Splitting tensile strength, Unit weight, Experiment.*

1.0 INTRODUCTION

Concrete is a man-made material used in a wide range of structural applications. It is produced by combining a binding agent, aggregate, with water-based components and mixing the mixture to stiffen it [Latifee, 2007]. Polystyrene is a widely used plastic material. The packaging sector generates this type of waste that pollutes the environment and harms the ecology. The cost of disposing of this trash is rising. Polystyrene's huge and bulky form necessitates a vast amount of room for disposal, and its treatment and disposal also pose a threat to the environment's sustainability. Millions of tons of waste polystyrene are created each year across the world. Polystyrene Foam is a non-degradable material. Polystyrene is virtually non-biodegradable in the event of land filling, taking millennia to degrade. Other disposal or treatment procedures have a negative ecological impact. However, because this material has properties such as sound proofing, insulation properties, and light weight, we can utilize it in the building projects, adding a new material for construction and a new environmentally beneficial means of disposal [Kole and Suryawanshi, 2017]. A number of important decisions must be made when selecting materials to combine into a design, like whether the items can be constructed into the specific and desired form, directional acceptance and sustaining the required shape while in use, and whether the requires maximum can be achieved and retained during use. It also analyzes whether the material is sustainable and if it is suitable with other materials [Askeland, 1996]. The purpose of this research is to investigate the usage of expanded polystyrene beads as a partial replacement for material in concrete, as well as its qualities such as compressive and tensile strength, as well as a strength comparison with conventional concrete. For this work, 10% to 30% of coarse aggregates were replaced by polystyrene.

2.0 METHODOLOGY

2.1 Materials Used

In the experiment, a variety of materials were used. Prior to conducting experimental work, the properties of materials are determined.

1. Cement
2. Fine aggregate
3. Coarse aggregate (Brick chips)
4. Coarse aggregate (EPS beads)
5. Water

2.2 Cement

The test was done using Ordinary Portland cement from a local store. Test on cement briefly described in below:

Normal consistency test:

The amount of water content that brings the cement paste to a standard condition of wetness is called "Normal Consistency."This test method confirms the ASTM standard requirements of specification C187. The typical range of values is 22% to 30% by weight of dry cement [ASTM, 2016].

Initial and final setting time test:

The term "initial setting time" refers to the beginning of the setting process of cement paste when the paste begins to lose its plasticity. "Final setting time" is the time elapsed between the moment when water is added to the cement and the paste completely loses its plasticity and attains sufficient stability to withstand a certain specified stress. This test method confirms the ASTM standard requirements of Specification C109 [ASTM, 2016].

Compressive strength of cement:

The mechanical strength of hardened cement is the property of this material, which is perhaps the most important one for its structural use. This test method conforms to the ASTM standard requirement of specification C150 [ASTM, 2017].

The same batch of cement was used for all tests as shown in Figure 1 and Table 1 lists the physical characteristics of Portland cement respectively.

Figure 1 Cement testing

Table 1 Ordinary Portland cement's physical characteristics

Physical property	Results obtained
Normal consistency (%)	29
Initial setting time (minutes)	95
Final setting time (minutes)	175
Days	**Compressive Strength (MPa)**
3 days	10.93
7 days	15.27
28 days	26.68

2.3 Fine Aggregate

Sand was acquired from Sylhet for the experimental investigation. To remove any larger particles, the sand was sieved with a 4.75 mm sieve and then rinsed to extract remaining dirt. Test of sand briefly described in below:

The fineness modulus of sand:

The Fineness Modulus of fine aggregates (sand) is an empirical value that can be calculated by summing the percentage of a sand sample that is retained on each of a given series of sieves, then dividing the total by 100 [Kosmatka et. al., 2002]. This test method conforms to the ASTM standard requirements of specification C136 [ASTM, 2006].

Specific gravity and absorption capacity test of sand:

This test method conforms to the ASTM standard requirements of specification C127 [ASTM, 2012].

Unit Weight Of Sand:

This test method conforms to the ASTM standard requirements of Specification C29 [ASTM, 2009].

Figure 2 shows the fine aggregate test and Table 2 lists the characteristics of the fine aggregate utilized in the experiment.

Figure 2 Test of fine aggregate

Table 2 Fine aggregate's characteristics

Test	Result
Fineness modulus	2.57
Bulk specific gravity (Oven-dry)	2.33
Bulk specific gravity (Saturated surface dry)	2.45
Apparent specific gravity	2.63
Absorption (%)	5
Unit weight (kg/m^3)	1564.15
(Saturated surface dry) Unit weight (kg/m^3)	1642.36

2.4 Coarse aggregate (Brick chips)

The size distribution of coarse aggregate is determined by the type of work. As per Indian Standard Specification IS: 383-1970, the course aggregate size used is 10mm to 20mm. ACI Committee 304 [1996] recommends, for aggregate with a maximum size of 20 mm, the bulk volume of dry-rodded coarse aggregate of 0.56 to 0.66 because the dry-rodded volume compensates automatically for differences in particle shape. The values cited are equally appropriate for rounded and angular aggregates. After washing, the brick chips were cleaned and the surface was dried to remove dust. The test of coarse aggregate (Brick chips) is briefly described below:

The Fineness Modulus Of Coarse Aggregate (Brick Chips):

This test method conforms to the ASTM standard requirements of specification C136 [ASTM, 2006].

Specific Gravity And Absorption Capacity Test Of Coarse Aggregate (Brick Chips):

This test method meets the requirements of ASTM specification C127 [ASTM, 2012].

Unit weight of coarse aggregate (brick chips):

This test method conforms to the ASTM standard requirements of Specification C29 [ASTM, 2009].

Figure 3 illustrates the results of the Brick chips test and Table 3 shows the characteristics of the brick chips utilized in the tests.

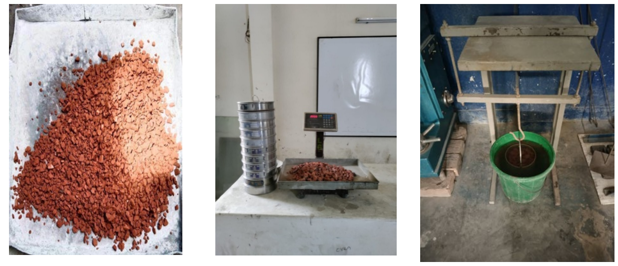

Figure 3 Test of coarse aggregate

Table 3 The characteristics of Brick chips

Test	Result
Fineness modulus	8.02
Bulk specific gravity (OD)	1.169
Bulk specific gravity (SSD)	1.646
Apparent specific gravity	2.235
Absorption (%)	13.75
Unit weight (kg/m^3)	990.65
SSD Unit weight (kg/m^3)	1126.86

2.5 Coarse aggregate (EPS beads)

The expanded polystyrene beads (EPS) utilized in experiment were provided by the Dhaka Insulation Company Limited, West Tengra, Demra, Dhaka, Bangladesh. Expanded polystyrene is made up of 98% air and 2% polystyrene material. The polystyrene used in the experiment was round, white, solid and had a very smooth surface. Figure 4 shows the EPS bead test in progress and Table 4 lists the results of the sieve analysis, specific gravity, water absorption, and unit weight tests.

Figure 4 Test of EPS beads

Table 4 Properties of coarse aggregate (EPS beads)

Test	Result
Fineness modulus	7.45
Bulk specific gravity (OD)	0.0137
Bulk specific gravity (SSD)	0.0137
Apparent specific gravity	0.0137
Absorption (%)	0.77

Unit weight (kg/m^3)	8.63
SSD Unit weight (kg/m^3)	8.69

2.6 Water

In this study, tap water collected from structural lab of UTTARA UNIVERSITY was used for mixing.

2.7 Mix Proportion

- Three mix ratio of 1:1:2, 1:1.5:3 and 1:2:4 by volume were used.
- As coarse aggregate, two different types of aggregates were used: one was brick chips and another one was EPS beads (expanded polystyrene beads).
- EPS beads were utilized as a substitute material for brick chips at levels of 0%, 10%, 20% and 30%. The water cement ratio was 0.45.

2.8 Specimen Preparation

In this study, total 144 concrete cylinders had been cast for test. For casting of those cylinders, 100 mm diameter and 200 mm height cylindrical mould has been used. To prevent segregation and ensure optimum compaction, concrete must be put with extreme caution. The techniques used to place concrete in its proper position have a significant impact on its uniformity, unit weight, and serviceability. Before casting, the cylinder mould was cleaned by a wire brush and then engine oil was applied on all sides of it. The concrete was carefully filled in two layers and tamped 25 times per layer with a 10 mm steel rod from a height of 457mm. After that the concrete was poured into each mould and leveled the top surface with the trowel. The materials required for sampling are shown in Figure 5 and Table 5 shows the specimen's specifics. The following design ratios by volume M20 (1:1.5:3), M15 (1:2:4), M25 (1:1:2), and water cement ratio by weight were used in this study.

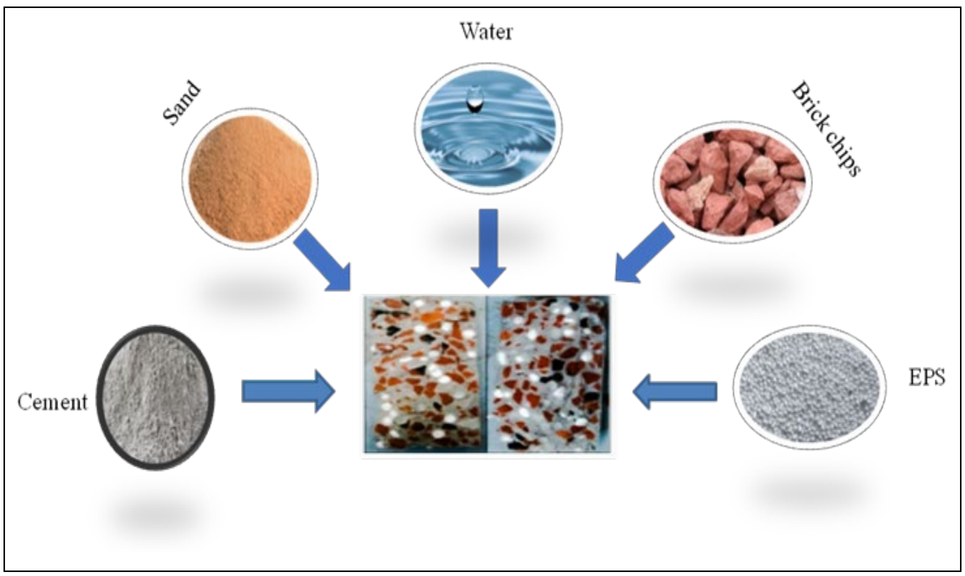

Figure 5 EPS based concrete cylinder

Table 5 Details of specimen

Sl. no.	Mix design ratio (by volume)	Water cement ratio (by weight)	Types of test	Age of test (days)	No. of cylinders tested with different percentage of EPS beads (%)				Total (Nos.)
					0	10	20	30	
1	1:1:2	0.45	Compressive strength	7	3	3	3	3	48
			Compressive strength	14	3	3	3	3	
			Compressive strength	28	3	3	3	3	
			Splitting tensile strength	28	3	3	3	3	
2	1:1.5:3	0.45	Compressive strength	7	3	3	3	3	48
			Compressive	14	3	3	3	3	

			strength						
			Compressive strength	28	3	3	3	3	
			Splitting tensile strength	28	3	3	3	3	
3	1:2:4	0.45	Compressive strength	7	3	3	3	3	48
			Compressive strength	14	3	3	3	3	
			Compressive strength	28	3	3	3	3	
			Splitting tensile strength	28	3	3	3	3	

2.9 Batching And Mixing Of Concrete

Batching is the process of measuring and combining concrete ingredients as per mix design. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. Batching of concrete is an important step in the concrete production process [Patel, 2020]. Batching of concrete is shown in Figure 6.

Figure 6 Batching of concrete

The ingredients were measured using the volume batching method in this investigation. Using a 100 mm × 100mm × 100 mm cubic mould, the volume of coarse aggregate, fine aggregate, cement and EPS beads was measured. In a 1:1:2 ratio, 1 dice cement, 1 dice sand and 2 dice brick chips were used. All of the materials total weight was calculated. The concrete mixing procedure is outlined below:

To begin with, clear the work surface to remove any unusual particles. Then, on the platform, spread the needed amount of coarse and fine aggregate, as well as the required amount of cement, uniformly over the sand layer. Dry components such as cement, sand, coarse aggregate and EPS beads were combined with shovels. These materials were mixed with shovels until they formed a uniform blend, then adding half of the required amount of water to the mix and turning it towards the middle. The mixture was vigorously blended until it had a uniform color and consistency. Added the remaining water and continued to mix until everything was smooth. Specimen mixture is shown in Figure 7.

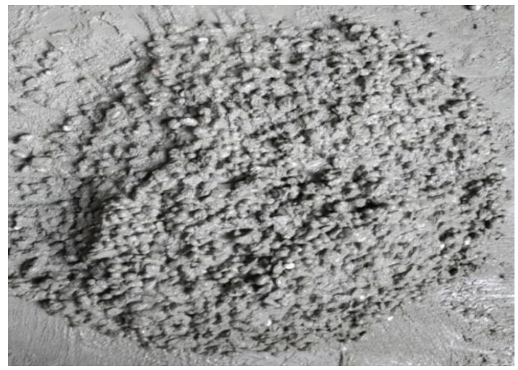

Figure 7 Mixing of concrete

2.10 Placing and Curing of concrete

Placing: Concrete must be placed with utmost attention to avoid segregation and guarantee optimal compaction. Concrete's uniformity, unit weight and serviceability are all affected by the techniques used to place it in its final placement. Figure 8 shows the placing of specimen.

Figure 8 Placing of concrete cylinder

Curing of concrete: The water curing method was used cure the concrete in this investigation. The moulds were opened twenty-four hours after casting, and on the cylinder, the date of casting, concrete proportions and various ratios were meticulously documented. Test specimens were placed in a curing tank for 7 days, 14 days, and 28 days respectively. The experimental samples were put in the curing tank as shown in Figure 9.

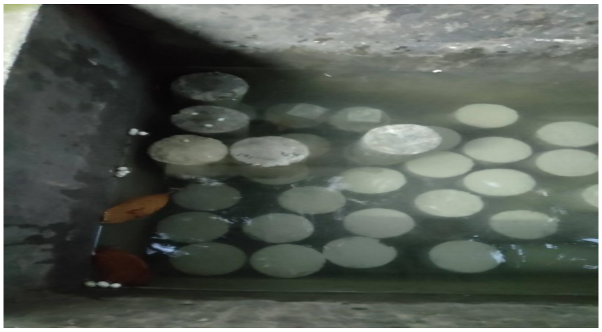

Figure 9 Curing of concrete cylinder

3.0 RESULT AND DISCUSSION

This section discussed the experimental test findings in terms of fresh and hardened EPS-based concrete.

3.1 Tests Performed On Fresh Concrete

Slump test

The test procedure is the most basic workability test for concrete, with low costs and quick results. The slump is carried out according to the ASTM C143 [2005] guidelines. Processing of the slump test is shown in Figure 10 and the slump test of concrete with EPS beads at various mixing ratios is shown in Table 6.

Figure 10 Slump test of concrete

Table 6 Slump test of concrete with EPS beads at various mixing ratio

Sl. no.	W/C	Mixing ratio	Replacement of EPS beads (%)	Slump (mm)
1	0.45	1:1:2	0	140
			10	120
			20	150
			30	155
2		1:1.5:3	0	82
			10	97
			20	125
			30	155
3		1:2:4	0	98
			10	105
			20	109
			30	149

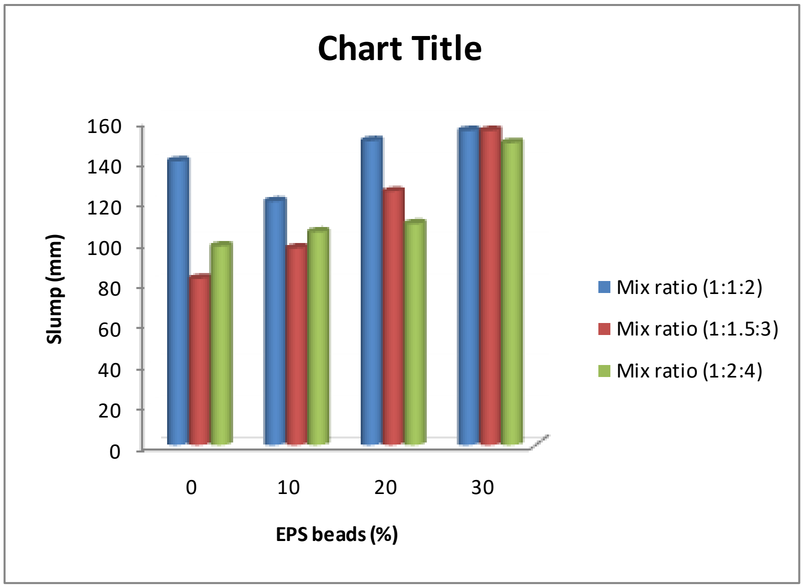

Figure 11 Slump value of concrete

To determine the mix's workability, a slump test was performed. As the number of EPS beads increases, so does the slump. The Slump test determines how workable (consistent) new concrete is. Slump values for mixes increased as the replacement amount of EPS was increased from 0% to 10%, 20%, and 30%. Figure 11 identified a minimum slump of 82 mm and a maximum slump of 155 mm.

3.2 Tests Performed On Hardened Concrete

Compressive Strength

The compressive strength of the suggested EPS concrete is its most significant mechanical strength characteristic. On a compressive testing machine, the compressive strength after 7, 14, and 28 days of curing in water was assessed. Table 7 provides the evolution of compressive strength determined by cylinder tests of control mixes and EPS concrete mixes. The compressive strength of EPS concrete has increased over time, similar to that of normal concrete. But the rate of growth was different. M15 grade concrete with 10% replacement of EPS achieved 28-day strength of 72% after seven days. Cook [1983] showed that EPS concrete developed about 95% of the 28-day strength in 7 days. In the study, cylinder specimens in grade M25, the unit weight was decreased by around 3.27% and the compressive strength by about 33.6% when coarse aggregate was replaced by 10% EPS. For cylinder specimens in grade M15, showed a maximum reduction in both unit weight and compressive strength with 30% EPS replacement, which was 17.02% and 66.4% less than the control mix, respectively. The addition of EPS beads significantly reduced the unit weight and compressive strength of concrete. The sharp decrease in strength stems from the fact that EPS particles are modeled as air voids and EPS concrete as cellular concrete [Miled et al., 2004]. Figure 12 shows the compressive strength test of the cylinder.

Figure12 Compressive strength test of cylinder

Table 7 Compressive strength of concrete with EPS beads at different days

Sl. no.	W/C	Mix ratio	Replacement of EPS beads (%)	Avg. compressive strength (MPa)		
				7 days	14 days	28 days
1	0.45	1:1:2	0	11.53	17.81	19.16
			10	7.46	9.69	12.65
			20	7.25	7.51	8.91
			30	5.68	7.27	7.69
2	0.45	1:1.5:3	0	10.85	13.04	15.64
			10	6.99	8.15	10.13
			20	6.79	6.95	7.94
			30	4.84	5.61	5.58
3	0.45	1:2:4	0	9.88	12.64	14.84
			10	6.63	6.92	9.20
			20	5.88	5.86	7.36
			30	4.17	4.57	4.99

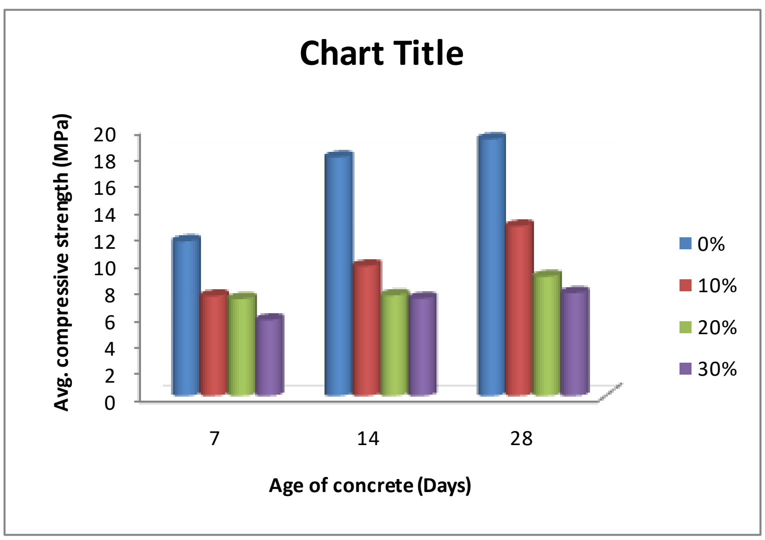

Figure 13 Compressive strength of concrete cylinder (1:1:2)

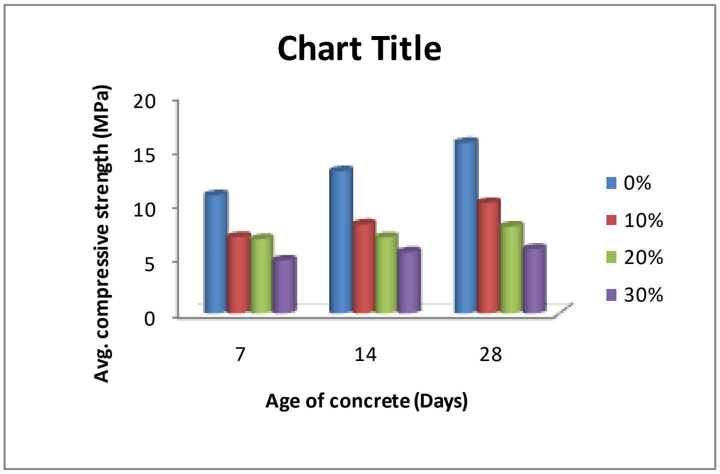

Figure 14 Compressive strength of concrete cylinder (1:1.5:3)

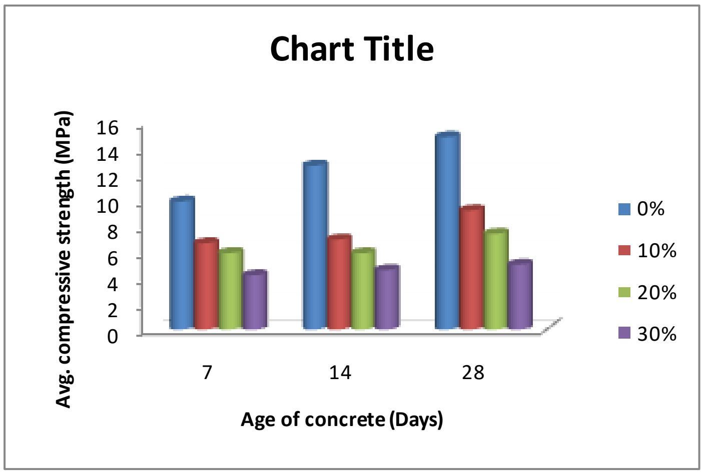

Figure 15 Compressive strength of concrete cylinder (1:2:4)

Figures 13, 14, and 15 show the results of the compression tests, which show that the compressive strength of all concrete mixes improves significantly with age. As the amount of polystyrene beads increases, the unit weight of concrete decreases and the compressive strength of concrete also decrease. Normal weight concrete has stronger compressive strength than EPS-based concrete at all ages. At 28 days, the compressive strength of 10%, 20% and 30% EPS-based concretes was found to be 66.4%, 46.0% and 40.0%, respectively, compared to the control concrete in Figure 13. At 28 days, the compressive strength of 10%, 20% and 30% EPS-based concretes was found to be 64.7%, 50.7% and 35.7%, respectively, compared to the control concrete in Figure 14. At 28 days, the compressive strength of 10%, 20% and 30% EPS-based concretes was found to be 61.9%, 49.4% and 33.6%, respectively, compared to the control concrete in Figure 15.

Splitting tensile strength

The tensile strength of composites is inferred from the splitting tensile strength. The examination is carried out by applying completely opposite compressive stresses to a concrete cylinder that has been placed on its surface in the testing equipment. The diametric plane is where fracture and splitting occurs. Table 8 displays the values of the splitting tensile strength of the control mix and the EPS mortar mixes after 28 days. For the cylindrical specimens, replacing the coarse aggregates with 10% EPS particles and using grade M25 resulted in a 7.8% reduction in the splitting tensile strength compared to the control mix. For cylinder specimens in grade M15 showed a maximum reduction in the splitting tensile strength with 30% EPS replacement, which was 50.77% less than the control mix. Evidently, the minimal effect that EPS particles have in preventing the spread of the single fracture is the cause of the decline in split tensile with the lowest EPS concentration. Figure 16 shows the cylinder's splitting tensile strength test.

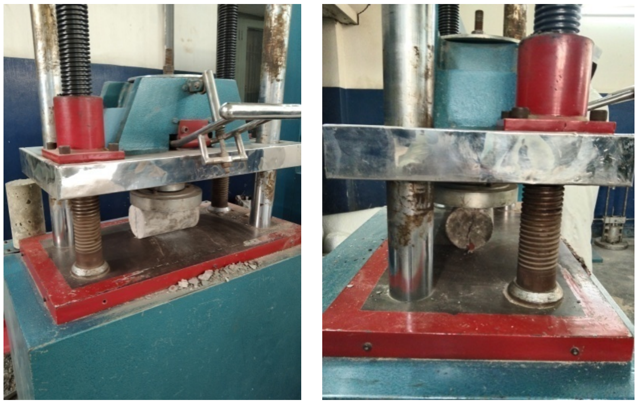

Figure 16 Splitting tensile strength test of cylinder

Table 8 Splitting tensile strength of concrete with EPS beads at 28 days

Sl. no.	W/C	Mixing ratio	Replacement of EPS beads (%)	Avg. splitting tensile strength (MPa)
1	0.45	1:1:2	0	2.05
			10	1.89
			20	1.84
			30	1.70
2		1:1.5:3	0	2.02
			10	1.84
			20	1.66
			30	1.56
3		1:2:4	0	1.95
			10	1.50
			20	1.22
			30	0.96

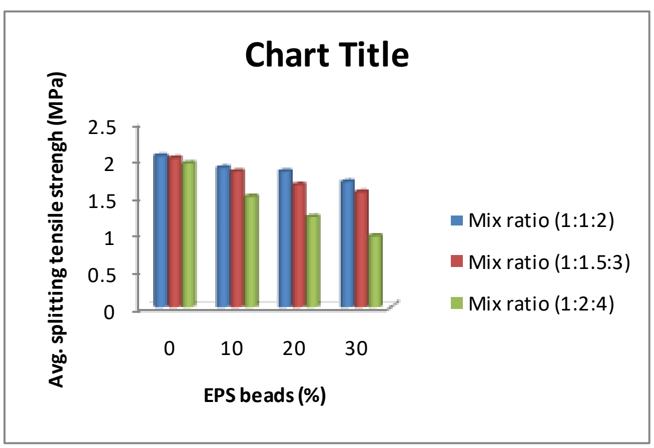

Figure 17 Splitting tensile strength of concrete cylinder at 28 days

The splitting tensile strength of concrete is used to estimate its tensile strength indirectly. Figure 17 shows the results of the splitting tensile strength test. The chart clearly shows that the higher the percentage of polystyrene beads in the concrete mix, the lower the tensile strength because the addition of EPS beads significantly lowered the concrete unit weight. When compared to control concrete at a mix ratio of 1:1:2, the splitting tensile strength of 10%, 20% and 30% EPS-based concretes at 28 days was 92.19%, 89.75% and 82.93%, respectively. When compared to control concrete at a mix ratio of 1:1.5:3, the splitting tensile strength of 10%, 20%, and 30% EPS-based concretes at 28 days was found to be 91.09%, 82.18% and 77.23%, respectively. At 28 days, it was discovered that EPS-based concrete had splitting tensile strengths of 10%, 20%, and 30%.

Unit weight

Unit weights are used to determine simple dimensional checks, weights and calculations, or weights in the air or water surge method, the weight of hardened concrete units. Analysis can also be performed to determine possible causes of deterioration or to assess the probability of future difficulties. One set (3 cylinders) of concrete specimens was taken out of storage after 28 days of curing for a unit weight test according to ASTM C642 [2013] for testing on a certain day. Before the test, the cylinder was removed from the water tank. The weight of each cylinder was determined. The machine also used calipers and a measuring tape to determine the diameter and height. As result, using the information above, compute the cylinder's unit weight. In this investigation, unit weight was tested on samples of four different percentages of the three ratios acquired in 28 days. The measuring of concrete's unit weight is shown in Figure 18 and the unit weight of EPS-based concrete with various mixing ratios is shown in Table 9.

Figure 18 Unit weight of concrete

Table 9 Unit weight of concrete with EPS beads various mixing ratio

Sl. no.	W/C	Mixing ratio	Replacement of EPS beads (%)	Avg. unit weight (kg/m³)
1	0.45	1:1:2	0	2012.24
			10	1946.28
			20	1794.39
			30	1739.55
2		1:1.5:3	0	1963.13
			10	1897.92
			20	1773.68

			30	1640.35
3		1:2:4	0	2005.43
			10	1798.37
			20	1794.23
			30	1664.12

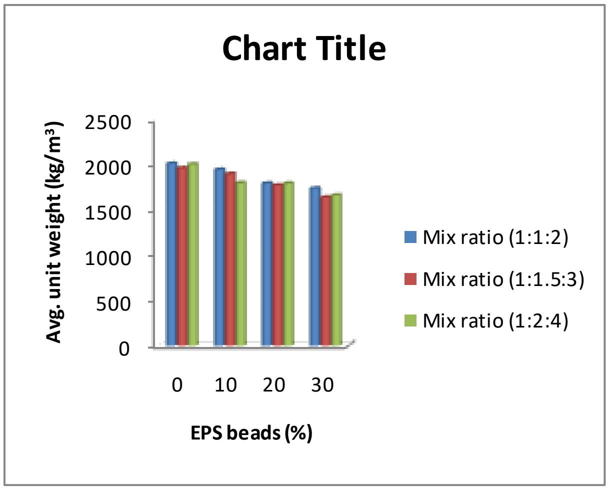

Figure 19 Unit weight of concrete at 28 days

Figure 19, the addition of EPS beads significantly lowered the concrete's unit weight. The replacement of coarse aggregates by 30% at a 1:1.5:3 mixing ratio resulted in a maximum unit weight decrease of 16.4%, lowering the unit weight to 1640.35 kg/m^3. A variance in unit weight was observed within the batch during the initial trial phases of the experimental study.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The compressive strength of EPS-based concrete was shown to be related to the concrete's unit weight. As a result, the compressive strength of EPS-based concrete increases as the concrete unit weight increases. The compressive strength of EPS-based concrete increased as the proportion of EPS beads decreased and increased as the brick chips percentage increased, but with the inclusion of EPS beads, the splitting tensile strength dropped. The findings suggest that EPS beads have the potential to generate lightweight concrete of moderate strength that might be employed in a variety of applications.

RECOMMENDATIONS

i. Test-fire deterioration of EPS-based concrete should be performed to determine the temperature at which it begins to degrade and the amount of harmful fumes emitted during thermal degradation.

ii. It is necessary to evaluate the thermal properties of EPS-based concrete.

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