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Enhancing the Use of Expanded Polystyrene (EPS) for Lightweight Concrete Wall Panels

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ABSTRACT

Concrete is widely used in for construction purposes due to many advantageous properties. Depending on the density, concrete can be categorized as either conventional or lightweight. However, incorporating sustainable and eco-friendly elements like Expanded Polystyrene (EPS) can reduce the weight of concrete resulting in construction material. The main objective of this research is to investigate the effects of the inclusion of EPS towards the physical characteristics of concrete such as compressive strength, flexural strength, density and water absorption. This research also aim to analyze the soundproofing capabilities of wall panels produced using EPS. The study focuses on evaluating percentages (10%, 15% and 20%) of EPS as aggregates in terms of their impact on mechanical properties, physical properties and soundproofing qualities, in lightweight concrete. A total of 36 cube samples measuring 100 mm x 100 mm x 100 mm were prepared for testing at both 7 day and 28-day curing periods. In addition, 12 wall panel samples measuring 100 mm x 100 mm x 500 mm and another four wall panel samples measuring 600 mm x 600 mm x 40mm for analysis. Findings of the research indicate that the desired targets were met for water absorption (10%) density (15%) and soundproof performance (20%). During the 28-day strength test, the compressive strength decreased by 21.86%, 30.57% and 35.56% when replacing 10%, 15% and 20% of the material respectively. Lightweight concrete achieved a value of 19.45 MPa with a replacement of only 10% EPS. However, the samples, with a replacement of 15% and 20% did not reach this compressive strength level. This study demonstrates that EPS can be effectively utilized in applications. There was a reduction for the flexural strength ranging from 13.42% to 27.89% compared to the control mix when replacing with EPS at rates of 10%, 15% and 20%. This study succeeded in producing the novel discovery of the use of EPS in contributing to reducing overall structure weight, which in turn helps decrease energy consumption during transportation and construction processes.

Keywords:
Expanded Polystyrene, Compressive Strength, Concrete, Lightweight, Wall Panel

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1. Introduction

Concrete is widely preferred as a building material, in today's society due to its advantages. To create concrete, cement, aggregates and grit are mixed with water. The initial stages of concrete preparation, placement, compaction and curing are central to the performance of Portland cement concrete in different applications [8]. An alternative option for aggregates is the use of expanded polystyrene (EPS) particles, which are biodegradable waste products that take a long time to decompose naturally. Expandable polystyrene (EPS), as an industrial material extensively used for energy saving in building exterior insulation system, helps to decrease the energy consumption from buildings by [20] and [21]. By incorporating EPS as the aggregate, concrete (LWC) can be produced, which is both stronger and lighter compared to concrete [7]. The application of EPS concrete has generated interest for structural purposes like slabs and wall panels [13]. In addition, the addition of fibers to the EPS lightweight concrete mix during mixing significantly reduces the settling of EPS beads and improves the uniformity of the mix as well [4].

When incorporating wall panels into a buildings structure there is an increase in the overall load primarily due to the weighty nature of these walls. The average densities of the wall panels range between 2200 and 2400 kg/m^3 [17]. The utilization of walls has contributed to reducing the dead loads on the structural components while enhancing acoustic insulation in the building [19]. With the escalation in construction material costs in Malaysia recently, this lead to significant impact economically.

Currently researchers and engineers who are forward thinking, in keeping up with development practices while also aiming to reduce costs can explore building materials [18]. One possibility is to replace materials with waste materials like expanded polystyrene, which can help cut the material costs and reduce the weight of concrete. According to [1], research has been conducted on producing concrete using aggregates such as waste polystyrene foam.

The aim is to enhance quality cut costs and promote the recycling of resources. Therefore this study was conducted to examine how the inclusion of expanded polystyrene affects the physical properties of concrete. This was achieved through tests measuring strength, flexural strength, density and water absorption. Additionally, an analysis was performed in a noise chamber using pressure measurements (in dB) to assess the insulation properties of concrete walls containing expanded polystyrene. This research aims to produce a new discovery of the use of EPS in contributing to the reduction of the overall weight of the structure, which in turn helps to reduce energy consumption during the transportation and construction process. This study also examines a detailed study on expanded polystyrene beads-based fly ash geomaterial (FAGM). The proposed geomaterial is prepared by blending EPS beads of different densities and contents in fly ash with cement as a binding agent [2].

2. Methodology

2.1 Materials

The research was conducted in Universiti Malaysia Perlis and the cement used in this research is Ordinary Portland Cement (OPC) grade 42.5. Field trials have shown that the cement can be used without any changes to the existing construction methodologies [9]. As per British Standard (BS) definition, the fine aggregate for materials can be either sand, manufactured sand or a combination of the two. In this investigation river sand with a size of 4.75mm is employed. Crushed stones with a maximum size of 20 mm are used as aggregates.

The proportions of EPS (Expanded Polystyrene) used in the mix are 0%, 10%, 15% and 20%. Previous studies advised against exceeding a replacement percentage of than 30% EPS in concrete. Higher percentages can adversely affect the mechanical properties and lead to reduced test results. EPS foam, as described by [14] and [16] is a plastic composed of small spherical shaped particles containing approximately 98% air and 2% polystyrene material consisting mainly of carbon and hydrogen elements. For this research EPS beads with sizes ranging from 2mm to 8mm, in diameter were utilized. Figure 1 below is the overview of the methodology employed in this research.

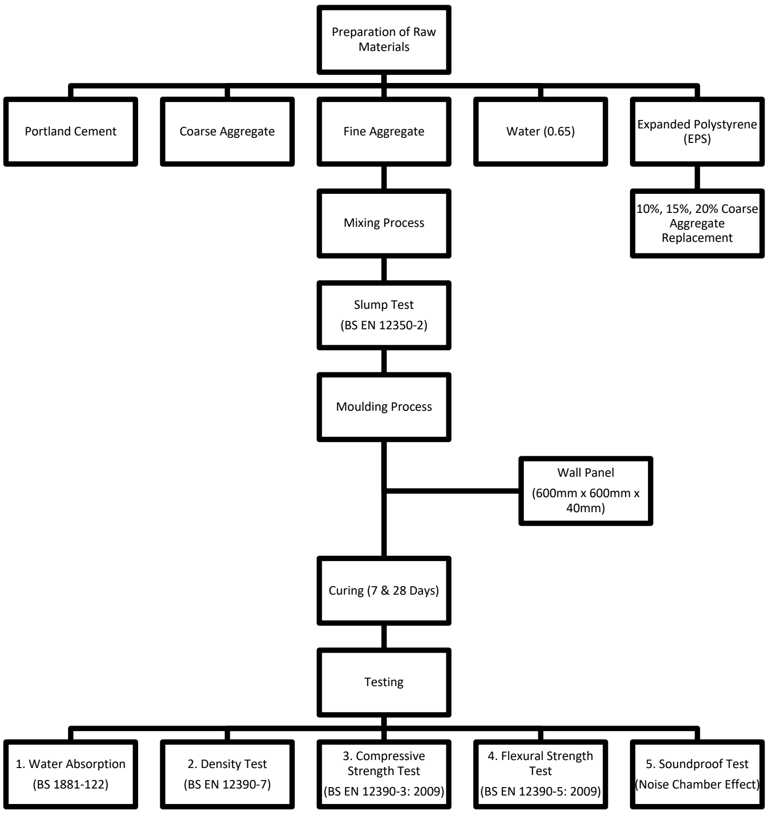

Fig. 1. Methodology research

2.2 Sample Preparations

The EPS used as partial replacement of coarse aggregate at the percentage of 10% (EPS 10%), 15% (EPS 15%) and 20% (EPS 20%). The total sample for this study is 52 samples for 7 and 28 - day periods. The samples were divided into 6 batches, 2 of which served as controls and the wall panel sample whereas the other 4 included varying percentages of EPS. The test used a sample that included EPS in varied amounts 0%, 10%, 15%, and 20%. The mix proportion for this study was determined by using the Design of Experiment (DOE). Expanded polystyrene percentage as an additive in the mixtures by volume of coarse aggregate. Table 1 below shows the details of the concrete mix proportions and Table 2 below shows the number of concrete specimens created for this experiment is displayed.

Table 1
Details of total sample and testing with EPS

Testing	Number of Concrete Specimens				Total
	Control sample	EPS 10%	EPS 15%	EPS 20%	
Water Absorption & Density	3	3	3	3	12
Compressive Strength Test (7 & 28 Days)	6	6	6	6	24
Flexural Strength (28 Days)	3	3	3	3	12
Wall Panel	1	1	1	1	4
Total					52

Table 2
Details of Mixture Proportions for Cube Specimens with EPS

Component (kg)	Control Group	Experimental Group		
	Grade 20	10%	15%	20%
Cement	2.91	2.91	2.91	2.91
Water/Cement Ratio	0.65	0.65	0.65	0.65
Water	1.89	1.89	1.89	1.89
Fine Aggregate	6.38	6.38	6.38	6.38
Coarse Aggregate	10.42	10.41	10.4	10.39
Expanded Polystryene	0	0.01	0.02	0.03

Water, coarse aggregates, fine aggregates, and EPS were introduced to a mixing drum and thoroughly mixed. The freshly mixed concrete was poured into the mould after being completely mixed. An oil coating is applied to the mould to provide a smooth surface before the moulding procedure. This study used cube moulds with dimensions of 100 mm x 100 mm x 100 mm for the compressive strength, flexural strength, density, and water absorption tests. Prism moulds with dimension 100 mm x 100 mm x 500 mm were used for the flexural strength. The wall sample that underwent the soundproof test was 600 mm x 600 mm x 40 mm in size. After the concrete had been completely cured, the demolding process is carried out the next day. The samples are subsequently placed in a water tank for 7 and 28 days curing prior to density testing.

2.2 Testing

The compressive strength of EPS samples was evaluated using the British Standard BS EN 12390 3. Universal Testing Machine (UTM) was utilized to assess the strength of the samples. Each test involved three cubes. Tests were conducted at 7 and 28 days to determine average compressive strength values.

For measuring the strength of concrete, the flexural strength test was used. Concrete measuring 100 mm x 100 mm x 500 mm was tested to evaluate its ability to withstand bending failure. This test was performed by British Standard (BS EN 12390 5;2019). A specimen was tested for 28 days, incorporating various EPS substitutions using a flexural testing apparatus. The density of hardened concrete was calculated to assess firmness. This assessment was carried out following BS EN 12390 7 specifications. The specimen density for the strength test was determined after both 7 and 28 days of curing.

Water absorption in specimens was examined by referring to BS 1881 122 (1983). A total of twelve specimens measuring 100 mm x 100 mm x 100 mm were used for this purpose. These specimens were cured for 28 days. To achieve a surface that was dry but still saturated, it was necessary to remove any water from the specimen after it had been taken out of the curing tank. The mass of the material, when reached this state known as "saturated surface dry," could then be determined. Once the specimen had been dried in an oven for three days at a temperature of 105 °C, its mass after drying was calculated.

For the creation of soundproofing in a given space, a noise effect chamber and temporary partition were utilized. Each of the four wall panels had dimensions of 600 mm x 600 mm x 40 mm. Three of these panels had substitutions made with expanded polystyrene aggregate varying at rates of 10%, 15%, and 20%. One panel served as a control measure, containing concrete. The installation of these wall panels took place at the center of the noise effect chamber. Sound pressure data was measured using a level meter (dB). During this investigation, various frequencies and separations were tested, including usage levels at distances measuring 0.15 mm, 0.66 mm, and 1.16 mm.

3. Results

3.1 Compressive Strength

The compressive strength of concrete containing proportionally more EPS was tested in this test on a cube of 100 mm x 100 mm x 100 mm. The compressive strength of the concrete was tested after 7 days and 28 days of curing. 24 samples in all were investigated, and the results of the compression strength test utilizing the Ultimate Tensile Machine (UTM) were reported.

Concrete containing EPS has less strength than conventional concrete, according to compression strength tests, which also indicate a quick decrease in strength. As can be seen in Figure 2 the compressive strength decreased dramatically as the replacement quantity expanded from 10%, 15%, and 20%.

Figure 2 shows that both the strength of the 7-day and 28-day specimens decreased with an increase in the EPS percentage. According to [16], the larger the amount of EPS in concrete, the lesser the compressive strength. This is because EPS beads have a lower specific gravity than coarse aggregates. Adding more beads also increased the number of voids in the mixture because beads have rounded surfaces rather than the angular surfaces of coarse aggregates, which enable higher interlocking [6,8]. Additionally, the strength increases from the 7 to the 28-day specimen. This is because there is more time for the hydration process to occur because of the longer curing time. The performance of concrete containing EPS beads increases when the curing time increases [12]. The highest compressive strength, 22.67 MPa, and 24.89 MPa was obtained by the control sample of the control group replacement at 7 days and 28 days. On the other hand, 12.05 MPa and 16.04 MPa were the lowest compressive strengths which were obtained by the 20% substitution.

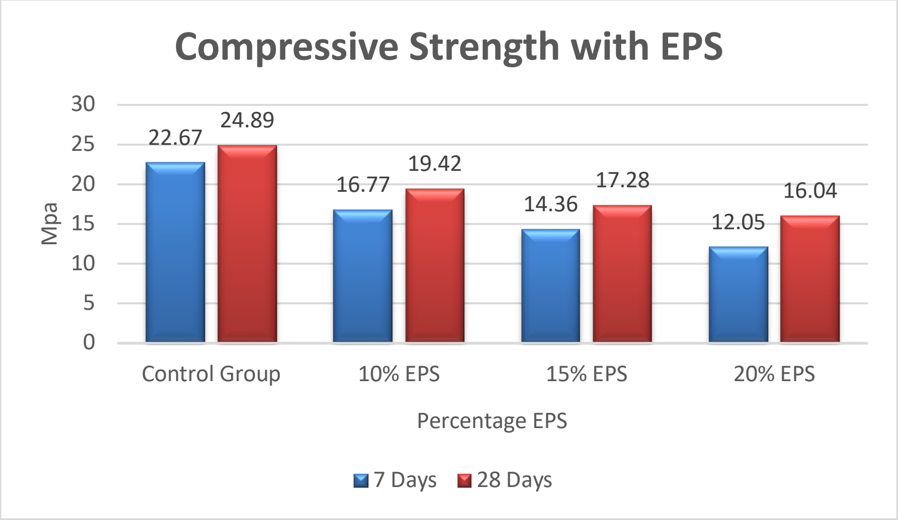

Fig. 2. Compressive strength of EPS

In comparison to the control specimen, the strength depicted in Figure 2 above decreased by 21.86%, 30.57%, and 35.56% for the partial replacement of 10%, 15%, and 20%, respectively, throughout the 28-day strength test. This indicates that the replacement of EPS in concrete by 10%, 15%, and 20% are not as strong as concrete, however, as the strength still exceeds the necessary threshold of 17 MPa, the specimen may be categorized as lightweight concrete. According to [3,11], Lightweight Aggregate Concrete (LWAC) must have a compressive strength of 17 MPa and a density range of 1350-2000 kg/m³.

3.2 Flexural Strength

In this test on a cube measuring 100 mm x 100 mm x 500 mm, the flexural strength of concrete with correspondingly added EPS was examined. After 28 days of curing, tests on the strength of the concrete were conducted. Overall, 12 samples were inspected, and the Ultimate Tensile Machine's strength test results were recorded (UTM).

Flexural strength tests, which also reveal a rapid decrease in strength, show that EPS-contained concrete has deteriorated more quickly than regular concrete. As shown in Figure 3, the compressive strength decreased significantly as the replacement quantity rose from 10%, 15%, and 20%.

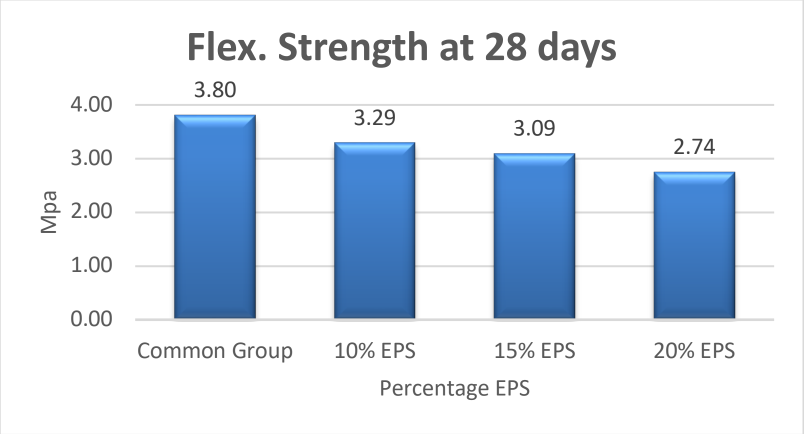

Fig. 3. Flexural strength with EPS at 28 days

Figure 3 above also shows that the flexural strength test was shown to decrease as the amount of EPS beads increased. The reduction was in the range of 13.42%, 18.68%, and 27.89% compared to the control mix for the partial replacement of 10%, 15%, and 20%, respectively. Because of the smooth and rounded surfaces of the EPS, there is less bonding between the aggregates and cement paste, which results in reduced bonding strength. Due to the aggregates' angular and rough structure, which promotes greater interlocking and increased strength, the control specimen, as can be seen, has the maximum flexural strength.

3.3 Density

A 100 mm x 100 mm x 100 mm cube was used for the density test, and as needed, EPS replacement was added. To determine the density, concrete samples were tested. In addition, 12 samples in total were examined, and the volume of the cube sample was divided by the weight of each sample after 7 days and 28 days of curing. As the replacement quantity rose from 10%, 15%, and 20%, as can be seen in Figure 3, the density test resulted in a decrease in the percentage of EPS beads in the mixture.

Figure 4 below shows that the density of the concrete falls as the amount of EPS beads in the mixture rises. This is a result of the EPS beads having a lower specific gravity than coarse aggregates. The density of the concrete decreased because the addition of more EPS creates more voids than the control mix. More air spaces will develop inside the concrete body, resulting in lower compressive strength and density than regular-weight concrete [10].

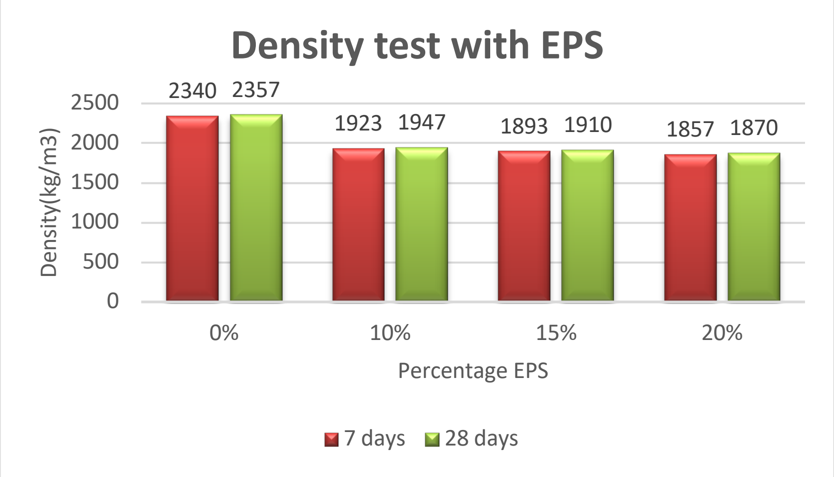

Fig. 4. Density test with EPS at 7 and 28 days

3.4 Water Absorption

For the water absorption test, a 100 mm x 100 mm x 100 mm cube was used, and EPS replacement was added when necessary. The amount of water that concrete would absorb after 28 days of curing was tested. After 24 hours in the oven, a total of 12 samples were assessed, and the percentage of water absorption was determined by comparing the weights of the wet and dry samples. The results of the water absorption test are shown in Figure 5, and show that the EPS samples used in this experiment meet the requirements. The figure shows for water absorption for EPS replacement at 0%, 10%, 15%, and 20% are 6.21%, 6.71%, 7.41%, and 7.86%, respectively. Even though the data are inconsistent, it is evident that when more water is added, there is a propensity for increased water absorption with an increase in EPS replacement level. From Figure 5 shown below, it can be seen that the water absorption increases with the increase of the EPS beads in the concrete. The control mix absorbs the least amount of water, whereas the 20% replacement absorbs the most. The water absorption parameters tend to decrease with the increase of the specific mass, being that the lower density presents significant water absorption, this shows that there is a loss of the beneficial characteristics of the use of EPS with low density [5] .This is explained by the fact that porosity reduces as EPS bead volume increases. Increased EPS beads cause the mixture to become more void-filled, which reduces density [15]. The spherical EPS beads shape makes the concrete pack poorly, increasing the end product's porosity.

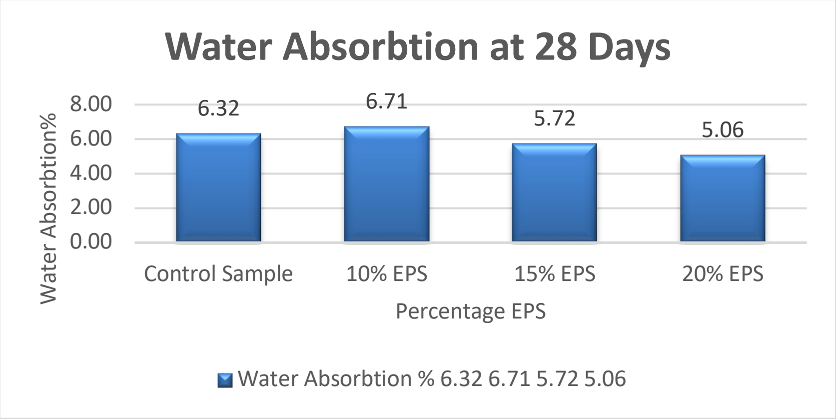

Fig. 5. Water absorption test with EPS at 28 days

3.5 Soundproofing Performance

For a total of 28 days, the material used in this test was allowed to cure in the curing tank. For this testing component, three distinct frequency classifications low, medium, and high are defined. The frequencies of 0.15 m, 0.66 m, and 1.16 m have gaps between them. The graph displaying the experiment's outcomes is displayed in the following Figures 6, 7, and 8 below.

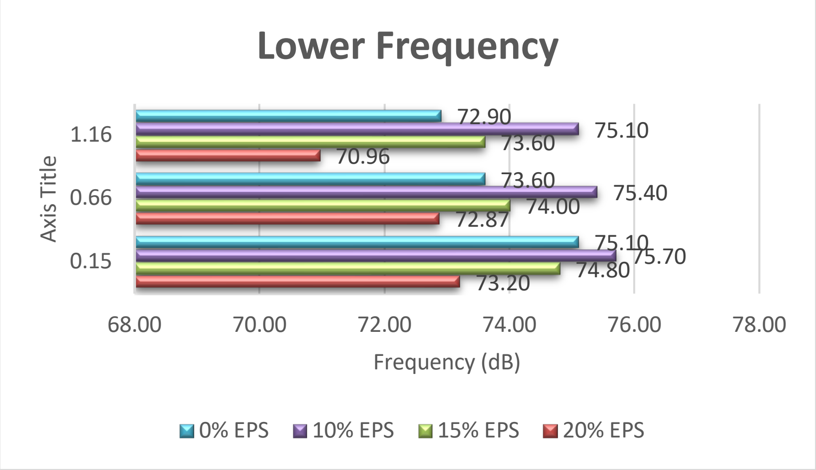

Fig. 6. Sound test for low frequency

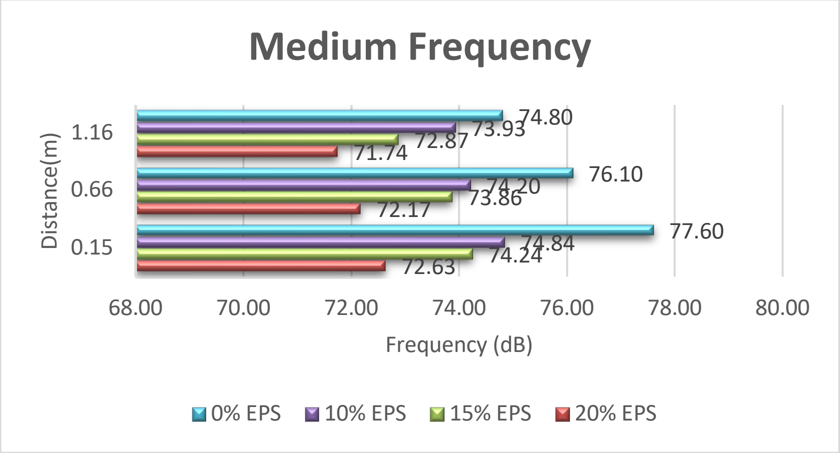

Fig. 7. Sound test for medium frequency

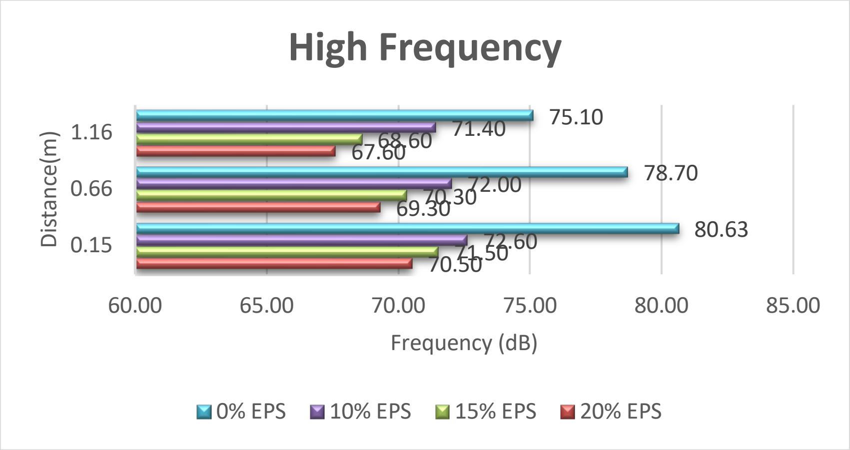

Fig. 8. Sound test for high frequency

Based on Figure 6 above, three different replacement percentages for the EPS and OPC concrete wall panels were looked at. The bar graph shows that at all distances, the sound intensity drops as the EPS% rises. The sound intensity produced by 0% EPS at a distance of 0.15 m is 75.70 dB. The sound pressure level drops to 75.10 dB with 10% EPS concrete. The sound intensity of concrete that contains 15% EPS decreases to 74.80 dB, and that of concrete that contains 20% EPS decreases to 73.20 dB. The sound level meter was evaluated once more using the same sample at a different distance. At 0.66 m, the intensity was collected at 75.40 dB for concrete with 0% EPS. The sound pressure level is reduced by 10% EPS concrete to 74.00 dB. The sound intensity drops to 73.60 dB for 15% EPS concrete and to 72.87 dB for 20% EPS concrete. After that, the same sample was used at a different distance. 75.10 dB is the sound pressure level for 0% EPS concrete measured at 1.16 m. With 10% EPS concrete, the sound intensity level reduces to 73.60 dB. For concrete that contains 20% EPS, the lowest sound intensity is 70.96%, and for concrete that contains 15% EPS, the lowest sound intensity is 72.90 dB.

Based on Figure 7, the pattern from the low frequency in Figure 6 is slightly different. The trend for 0.15 m, 0.6 m, and 1.16 m is rapidly declining from 0% to 20% EPS concrete. Figure 8 shows that the trend is slightly different from the mid-frequency in Figure 7. The trend for 0.15 m significantly decreases between 10% EPS concrete and 0% EPS concrete. Between 0% and 20% EPS concrete, the values of 0.6mm and 1.16m are significantly decreased. High-frequency sounds created by high pitch may make the occupants of affected building uncomfortable.

This suggests that OPC concrete's capacity to absorb sound may be improved by the addition of EPS material. This, in addition to the insulating qualities of the EPS aggregate particles, is responsible for the improvement. As a result, the insulating properties and trapped air, which lessen and absorb sound vibrations, increase the EPS aggregate's soundproofing capabilities.

4. Conclusions

In this study, the impacts of adding various EPS bead percentages were examined using the testing findings on cube, prism, and wall panel samples. There is a description of the test results for density, water absorption, compression strength, flexural strength, and soundproofing. One can draw inferences based on the results obtained after 7 and 28 days of treatment. To determine how expanded polystyrene (EPS) influences mechanical and physical qualities, the grade M20 compression strength test and flexural strength test both fell short of the target objectives. Nevertheless, with EPS percentages of 10% and 15%, the strength for lightweight concrete is achieved with a strength of more than 17 MPa. Based on the findings, this type of concrete can be categorized as lightweight concrete due to a decrease in density. Last, but not least, the study has accomplished the aim to make EPS-based lightweight concrete wall panels that are soundproof. By raising the EPS replacement percentage, the sound may be further reduced. This additional piece of EPS concrete can function as a partition wall and lower the energy needed for transportation and construction. This study succeeded in producing the novelty discovery of the use of EPS in contributing to reducing overall structure weight, which in turn helps decrease energy consumption during transportation and construction processes.

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