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Original Article

Evaluation of Lightweight Concrete Using Expanded Polystyrene Aggregate with Montmorillonite Calcined Powder

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Abstract - *Expanded Polystyrene (EPS) is a lightweight, non-biodegradable waste that causes environmental pollution and can be utilized in concrete. In addition to consuming a lot of energy and raw materials, the production of cement releases roughly 7% of the CO_2 gas that causes global warming. Montmorillonite calcined powder is an eco-friendly pozzolanic material. In this study, natural coarse aggregate is replaced by expanded polystyrene in the proportions of 0% to 25% with a 5% gradual increment, and ordinary portland cement is replaced by montmorillonite calcined powder in the proportions of 2% 4% with arriving design mix of M60 grade. Additionally, to increase the concrete's strength, steel fibres are added to the concrete in a 1% ratio. It is observed that the 10% replacement of EPS with 4% of MMT gives the optimum value in compressive, split tensile and flexural strength.*

Keywords - *Expanded Polystyrene (EPS), Lightweight aggregates, M60 grade, Montmorillonite Calcined Powder (MMT), Steel fibres.*

1. Introduction

Concrete's many qualities, including its availability, durability, economic effectiveness, and ease of on-site manufacturing, make it a valuable material for a variety of construction applications, from building foundations to bridges and dam constructions. Concrete is a heterogeneous material that consists of cement, fine aggregate, and coarse aggregate, which are derived from natural sources The demand for these natural sources was increasing from day to day with the increase in urbanization of the country.

To optimize natural resources and costs as well as to minimize CO_2 emissions into the environment, much research has been done to replace concrete material. Artificial lightweight aggregates can be used to generate structurally lightweight concrete; the major drawback is the high cost of these aggregates. Using EPS as aggregate makes the production of lightweight concrete economical and environmentally friendly.

In addition to the lightweight property, EPS has other beneficial properties, such as high thermal insulation, high sound absorption, and super low water absorption [17]. In addition to being used as a coarse pavement foundation material, it can be used as an energy-absorbing material for subterranean military facilities, fenders for offshore oil platforms, cladding panels, lightweight walls, floating marine structures, and marine flooring [2]. Because lightweight concrete requires less maintenance and has a lower dead weight than traditional concrete, its demand is currently growing quickly on a global scale. Polystyrene aggregate concrete is an intriguing lightweight concrete option since it can be customized to meet specific requirements by varying the characteristics of its elements, such as the polystyrene volume fraction and bead size [18].

Conversely, cement in concrete is increasing [19]. However, some specialists have questioned its effects on the environment. Considering the greenhouse gas emissions from the manufacture of Portland cement, the following objection was made [20]. According to previous studies, montmorillonites are comparatively good pozzolanic materials [21]. This present investigation attempts to examine the impact of EPS as a coarse aggregate and montmorillonite as cement in concrete. Tests on concrete's workability, split tensile strength, compressive strength, and flexural strength were conducted to determine its strength.

Fig. 1 Expanded Polystyrene (EPS)

Fig. 2 Montmorillonite Calcined powder

1.1. Research Problem and Significance

The need for long-term improvements in lightweight concrete compositions is the main research issue this study attempts to solve. The use of natural aggregates in conventional concrete manufacturing leads to resource depletion and environmental harm. Innovative solutions are required to address the considerable environmental problem posed by the disposal of EPS waste. In addition, the usage of cement in the building sector is growing daily, and the process of producing cement emits greenhouse gases into the atmosphere. In order to lessen environmental pollution, the cement substitute is essential. The goal of this study is to investigate the viability and advantages of combining EPS and MMT into LWC, addressing the need for sustainable building materials as well as the environmental problem of EPS disposal. Lightweight aggregates are usually an absolute necessity for lightweight concrete. Recent research has investigated the use of EPS as aggregates in concrete, focusing on the material's mechanical qualities and sustainability in the environment. They have demonstrated that the low density of EPS aggregates contributes to the reduction of self-weight in concrete constructions. However, the strength of concrete is severely compromised when the replacement proportion of EPS increases [22]. Consequently, the purpose of this study is to strengthen and improve the bonding of lightweight concrete using EPS, MMT, and steel fibre.

1.2. Objectives of the Study

The current study intends to carry out a feasibility analysis of strong, lightweight concrete. The materials used in the investigation are expanded polystyrene aggregate, montmorillonite calcined powder, steel fibre, superplasticizer, cement, natural coarse aggregate, and fine aggregate. The following are the study's objectives:

- To examine the physical characteristics of various materials that are utilized in this investigation.
- To arrive at the mix design of M60 grade with various mix proportions using EPS and montmorillonite calcined powder as a replacement in concrete.
- To find the workability of concrete with varied mix proportions for the ease of placement without segregation.
- To assess the split tensile, compressive, and flexural strengths of concrete with different mix ratios.

2. Literature Review

Firas Jawad Kadhim *et al.* (2023) investigated the viability of creating Light Weight Aggregate (LWA) with waste-EPS and mortar. The outcomes show that the EPS is useful for LWA. The range of 588 to 790 kg/m^3 is found for the loose bulk density, satisfying the LWA specification of ASTM C330. Because of the voids in the LWA, the water absorption value achieved is slightly greater than the usual aggregate, ranging from 6.45 to 14.05%. When LWA with a superplasticizer was used to make LWAC, the concrete's compressive strength was greater than that of LWA concrete without a superplasticizer. 21 MPa was the maximum compressive strength recorded for LWAC.

Mazizah Ezdiani Mohamad et al. (2022) investigated the various mixtures wherein EPS beads replaced all of the coarse aggregates at 100%, and a blend of 20%, 25%, and 30% FA and SF took the place of cement. The results demonstrate that the use of silica fume and fly ash can further reduce the density of EPS lightweight concrete. To improve the EPS lightweight concrete's characteristics while it is still fresh, add fly ash and silica fume. 5% SF, 20% FA is the ideal mix ratio for EPS lightweight concrete, producing a compressive strength of 12.8 N/mm^2. Fly ash or silica fume can be used to EPS lightweight concrete to increase its compressive strength.

Ram Kumar P et al. (2019) examined the impact of using partially substituted expanded polystyrene beads for fine aggregate in lightweight concrete, enhanced the density and compressive strength of polystyrene beads, which are introduced at intervals of 10% of the total volume of fine aggregate, are investigated. According to the results, it is possible to replace an optimal 40% of the Expanded Polystyrene beads with a volume of fine aggregate, giving M20 grade concrete a strength of 21 N/mm^2 and a density of 19 kN/m^3.While M20 concrete is preferred, it can be utilized for simple concrete constructions. Parveen Berwal et al. (2023) studied the 10% (of the total volume of the fine total) of expanded polystyrene beads added, and properties including compressive strength and viscosity are examined. Based on the obtained results, it can be observed that an ideal replacement volume for 40% of the expanded polystyrene beads is a volume of fine overall, resulting in a strength of 21 N/mm^2 and viscosity of 19 kN/m^3 for concrete M20 grade. When tested for seven and twenty-eight days, M20 concrete is found to be satisfactory for usage in basic concrete constructions.

Rajesh Kumar. V et al. (2018) investigated the granular waste product of expanded polystyrene, which is utilized as a lightweight aggregate in lightweight structural concrete. The polystyrene aggregates can be effectively employed to create a lightweight material, according to the experimental results. The outcomes also show that polystyrene waste aggregate concrete has good workability and strength properties that are on par with traditional concrete.

Tek Raj Gyawali (2022) investigated lightweight concrete made using EPS beads as aggregates. The findings show that the workability, density, Young's modulus, split tensile strength, flexural strength, and compressive strength of mortar/concrete are significantly reduced when EPS is added. To create structural EPS concrete, up to 30% of the EPS content can be used. Non-structural EPS concrete can be made when the composition is increased above 30%.

Anjan B K et al. (2019) studied the strength properties of EPS are improved by replacing fine aggregates at the ideal dosage for 40% of the EPS beads. Moreover, the weight of cement modifies the fraction of polyester fibres. The study indicates that a 0.30 percent polyester fibre-to-cement weight ratio is optimal. After 28 days of curing, this yields a split tensile strength of 8 N/mm^2, an average compressive strength of 26 N/mm^2, and a density of 18 kN/m^3.

Daniela González Betancur et al. (2019) studied the impact of using lightweight Expanded Polystyrene (EPS) in place of fine aggregate in a simple concrete mixture that has been partially changed with Fly Ash (FA). Destructive and non-destructive testing was performed on cylindrical specimens to assess their mechanical and physical characteristics, including compressive strength, density, and elastic dynamic modulus. Moreover, X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Fourier Transform Infrared Spectroscopy (FTIR) were used to characterize the cementing material and EPS. The results show that between 10% and 30% of aggregate substitution is the range that ensures both a substantial reduction in density and a minimal reduction in compressive strength.

C. H. R. Carvalho and L. A. C. Motta (2019) studied Expanded Polystyrene (EPS) added to lightweight concretes to improve their structural wall uses. In comparison to the reference concrete, the addition of EPS caused a drop in compressive strength that reached roughly 40% for type A concretes and nearly 50% for type B concretes. With the addition of EPS, the void ratio and absorption by immersion rose in all mixes. The results of the thermal tests demonstrated that all EPS-containing concrete was more successful than reference concrete in lowering temperature. When compared to reference concrete, the concrete with the highest recycled EPS (CBR) content performed the best, displaying a drop in interior compartment temperature of up to 6.0 °C.

Galina Erikovna Okolnikova et al. (2022) investigated an aggregate, Expanded Polystyrene Granules (EPG) that can be utilized to create Light Weight Concrete (LWC). Based on the experimental studies, it can be said that the EPG concrete's compressive strength increased up to a certain degree as the quantity of scattered hybrid fibres increased. Therefore, this study confirms that the optimal outcomes are obtained with basalt and steel fibre fractions of 0.5%, 1.0%, and 1.5%. The concrete cubes strengthened to their greatest degree, as expected, after 28 days in the curing tank. In addition, the results show that, in comparison to the other percentages of BF and SF taken into consideration in this study, 1% to 1.5% of BF and SF content produced higher compressive strength values.

Aqil MK Almusaw (2021) investigated the expanded polystyrene waste-containing cement mortar's mechanical and thermal qualities. The density dropped by 39.3% to 1290 kg/m^3, the thermal conductivity dropped by 70.5% to 0.212 watt/k.m, the compressive strength dropped by 85.1% to 5.11 MPa, and the flexural strength dropped by 74.4% to 2 MPa as a result of the weight reduction and volume increment of the EPSw 60% mortar. These mechanical and physical characteristics are suitable for a variety of civil engineering projects, particularly when it comes to the production of cement boards for outdoor use, which will increase their heat insulation and reduce their need for electricity.

Akshay Shetty and Neethu Urs (2020) studied the result of partially substituting expanded polystyrene beads for particles in the concrete, which makes it lighter than regular concrete. Although polystyrene is resistant to acids and bases and is chemically very inert, it can be readily dissolved in a wide range of aromatic hydrocarbon and chlorinated solvents. Despite the components being pulled out of 1 m^3 of regular concrete, the volume decreased because of the compressibility of the Polystyrene beads. Polystyrene does not bond well with cement or concrete because it repels water. In addition to decreasing the surface area, pre-coating with a natural clay binder enhanced the ability of expanded polystyrene to bind with concrete. Crushed polystyrene can be disposed of effectively by mixing it with concrete.

Punkesh Kumar (2022) examined how EPS affected the concrete's durability, workability, and mechanical qualities. According to the research's findings and analysis, the workability, tensile strength, flexural strength, and compressive strength all reduced as the volume of EPS dosage increased. The tensile strength increased up to 10% EPS before declining, making the EPS concrete weaker. It can be used for structural elements with low strength.

Rafaa Mahmood Abbas and Rawah Khalid Rakaa (2023) investigated through an experimental study the flexural behaviour of lightweight beams composed of Expanded Polystyrene (EPS) concrete reinforced with steel fibres and rebar. The test results demonstrated that polystyrene EPS beads considerably decreased the mechanical qualities of the hardened concrete, with some improvement occurring when steel fibres were introduced to the concrete mixture. The polystyrene EPS beads considerably decreased the flexure strength of EPS-LWT concrete beams. Additionally, the results showed that the steel fibre reinforcement had a significant positive impact on the evaluated beams' flexure strength. Gamachu Wakoya Fufa et al. (2021) examined the strength and durability of concrete by partially substituting waste Khat Husk Ash (KHA), Calcined Montmorillonite Clay Powder (CMMT), and OPC. The outcomes demonstrated that when OPC was partially replaced with calcined MMT clay powder and KHA, the consistency and setting time remained within the ASTM C-191 standard specifications. Furthermore, as the replacement was increased, the split, flexural, and compressive tensile strengths steadily declined in comparison to the control specimen. The best proportion of waste KHA and calcined MMT clay powder to replace OPC content in typical concrete mix manufacturing was found to be up to 15% by weight. According to the benefit-cost study, utilizing OPC in conjunction with KHA and calcined MMT clay powder is more economical than utilizing OPC alone.

2.1. Research Gap

The literature study above makes clear that there are many opportunities for EPS to be employed as a lightweight component in a concrete mix due to its low density. Even though EPS does not have the same mechanical and physical properties as aggregate, previous studies have indicated that it may be used as a coarse aggregate in different proportions for LWC. However, there are not many studies that specifically address how to enhance the strength properties of EPS-based lightweight concrete by incorporating different materials. This study investigates the use of lightweight Expanded Polystyrene (EPS) in place of coarse aggregate. Newly mixed EPS-based concrete experiences problems, including segregation, which impairs its workability because it is lightweight and hydrophobic. Ideal replacement quantities of aggregate have a positive influence on concrete's strength, and excessive replacement weakens it. Although research on EPS as a replacement is encouraging, it mostly concentrates on lowering density and presents difficulties with strength loss. In order to improve bonding and address segregation, this research evaluates the characteristics of lightweight concrete's structural performance with different amounts of EPS (0%, 5%, 10%, 15%, 20%, and 25%), steel fibres, MMT, and superplasticizer. The results demonstrate the low density and better mechanical strength of EPS-based concrete with steel fibres and MMT, and an ideal lightweight concrete design mix is suggested.

3. Materials and Properties

3.1. Cement

The control mix produced by the OPC with ultra tech 53 grade satisfies the requirements of IS 12269-2013. BIS 4031-1988 & 1999, used to measure the physical properties of cement and the results are tabulated in Table 1.

Table 1. Characteristics of cement

Property	Value
Fineness of cement	1.17
Specific gravity	3.17
Initial setting	34min
Final setting	280 min
Average consistency	30%
Soundness	2.8 mm

3.2. Montmorillonite Calcined Powder (MMT)

Montmorillonite contains mostly SiO_2 in its chemical composition. This kind of SiO_2 can react with Ca $(OH)_2$ to form Calcium Silicate Hydrates (C-S-H), which are what give hydrated cement paste its strength [16]. The features of MMT are shown in Table 2.

Table 2. Characteristics of MMT

Property	Value
Fineness	2.1
Specific gravity	2.46
Average particle size	5-6µm
Density	2100kg/m^3

3.3. Fine Aggregate

Using a 4.75mm IS sieve, fine aggregate made from locally available sand is employed by IS 383 - 1970 requirements. The properties are shown in Table 3.

Table 3. Characteristics of fine aggregate

Property	Value
Modulus of fineness	3.94
Sp. gravity	2.73
Water absorption %	1.24
Unbound bulk density	1354 kg/m^3
Bulk density after compacting	2589 kg/m^3

3.4. Coarse Aggregate

The present work utilized coarse aggregate consisting of locally accessible hard granite shattered stones no larger than 12.5 mm. According to the process outlined in BIS 2386-1963 (reaffirmed 2002), the physical characteristics of aggregates were assessed, and the findings are shown in Table 4. The outcome demonstrates that aggregate characteristics meet the standards established by BIS 383-1970 (Reaffirmed 2011).

Table 4. Properties of coarse aggregate

Property	Value
Modulus of fineness	6.71
Specific gravity	2.58
Water absorption %	1.43
Unbound bulk density	1342 kg/m³
Bulk density after compacting	1486 kg/m³

3.5. Expanded Polystyrene

EPS is a thin, fully recyclable material. These are made up of tiny, round particles and are light in weight. Since using lightweight concrete, there are several advantages to consider. These include reduced loads during construction, decreased structural self-weight, and improved thermal resistance. The properties of EPS are shown in Table 5.

Table 5. Characteristics of EPS

Property	Value
Water absorption	1.1 %
Specific gravity	0.72
Density	15 kg/m³

3.6. Mix Design

The mix design obtained for the amount of cement, fine aggregate and coarse aggregate is calculated based on IS: 10262-2009. Table 6 shows the quantity of materials for one cubic meter of concrete. The concrete contains cement, montmorillonite, fine aggregate, coarse aggregate, EPS, Super Plasticizer (SP) and water.

The montmorillonite replacement at 2% and 4 % by the weight of cement was used. EPS as a partial replacement for coarse aggregate at 5, 10, 15, 20, and 25% were used, and a 1% volume fraction of steel fibre was used. Table 7 shows the mix proportions of the concrete mix.

Table 6. Quantity of materials

Materials	Quantity
Water	141 litre
Cement	470 kg
Fine aggregate	696 kg
Coarse aggregate	1023 kg
Super Plasticizer	1.5%

Table 7. Mix design

Mix ID	Binder				Fine Aggregate		Coarse Aggregate				Water	SP	Steel fibre
	OPC		MMT				NCA		EPS				
	%	kg/m³	%	kg/m³	%	kg/m³	%	kg/m³	%	kg/m³	litres	%	%
CC	100	470	0	0	100	696	100	1023	0	0	141	1.5	0
5E	100	470	0	0	100	696	95	971.85	5	51.15	141	1.5	1
10E	100	470	0	0	100	696	90	920.70	10	102.3	141	1.5	1
15E	100	470	0	0	100	696	85	869.55	15	153.45	141	1.5	1
20E	100	470	0	0	100	696	80	818.40	20	204.60	141	1.5	1
25E	100	470	0	0	100	696	75	767.25	25	255.75	141	1.5	1
2M5E	98	460.6	2	9.4	100	696	95	971.85	5	51.15	141	1.5	1
2M10E	98	460.6	2	9.4	100	696	90	920.70	10	102.3	141	1.5	1
2M15E	98	460.6	2	9.4	100	696	85	869.55	15	153.45	141	1.5	1
2M20E	98	460.6	2	9.4	100	696	80	818.40	20	204.60	141	1.5	1
2M25E	98	460.6	2	9.4	100	696	75	767.25	25	255.75	141	1.5	1
4M5E	96	451.2	4	18.8	100	696	95	971.85	5	51.15	141	1.5	1
4M10E	96	451.2	4	18.8	100	696	90	920.70	10	102.3	141	1.5	1
4M15E	96	451.2	4	18.8	100	696	85	869.55	15	153.45	141	1.5	1
4M20E	96	451.2	4	18.8	100	696	80	818.40	20	204.60	141	1.5	1
4M25E	96	451.2	4	18.8	100	696	75	767.25	25	255.75	141	1.5	1

4. Results and Discussion

4.1. Workability

To determine workability, the slump cone test was performed in accordance with IS 1199-1959. The results indicate that all examples of EPS concrete had slump values between 83 and 98 mm, as indicated in Table 8. Therefore, the quality of each of these specimens is sufficient. The addition of superplasticizer helps to boost the workability of concrete and retain it without the need for additional water. The standard concrete mix's slump value without any replacements was measured to be 80 mm. As can be observed, the concrete mix 25E contains 25% EPS and 1% steel fibre exhibited superior performance in workability. The slump value obtained for the concrete mix 25E was 98 mm which is about 22.5% higher than the normal concrete mix CC. The 4M5E mix exhibited a relatively lower slump value than the 25E mix but the slump value obtained was still higher than the normal concrete mix. Figure 3 displays the variance of the workability of concrete.

4.2. Density Test

During the laboratory density test, the concrete cube's unit measurement was kg/m^3. The ASTM C138 served as the basis for the experiment. After 28 days of curing, the weight of the concrete specimen with a volume of 0.001 m^3 was measured in the lab using an electronic scale.

$$\text{Density}, \frac{kg}{m3} = \frac{Wi}{V}$$

Where, Wi = 28 day weight of the submerged sample, kg
V = The concrete cube specimen's volume, m^3

Table 9 shows that the range of total density for concrete mixtures was 2296 kg/m^3 to 2518 kg/m^3. As the percentage of EPS increases, concrete's density falls. Compared to traditional concrete, EPS concrete has a lower density. 4M5E mix shows a higher density of 2474 kg/m^3 in contrast to all other mixes containing EPS. Conversely, the 25E mix has a relatively lower density of 2296 kg/m^3.

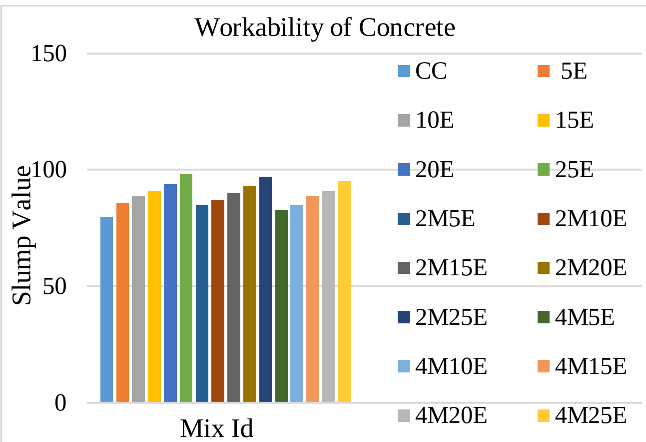

Fig. 3 Workability of concret

Table 8. Workability test

Mix ID	Slump Value (mm)
CC	80
5E	86
10E	89
15E	91
20E	94
25E	98
2M5E	85
2M10E	87
2M15E	90
2M20E	93
2M25E	97
4M5E	83
4M10E	85
4M15E	89
4M20E	91
4M25E	95

Table 9. Density test

Mix ID	Specimen Weight (kg)	Density (kg/m^3)
CC	8.50	2518
5E	8.31	2462
10E	8.09	2397
15E	7.90	2340
20E	7.83	2320
25E	7.75	2296
2M5E	8.32	2465
2M10E	8.10	2400
2M15E	7.95	2355
2M20E	7.89	2337
2M25E	7.78	2305
4M5E	8.35	2474
4M10E	8.21	2432
4M15E	8.10	2400
4M20E	7.95	2355
4M25E	7.80	2311

4.3. Compressive Strength

Compressive strength testing was done in compliance with IS: 516-1959. The compressive strength of mixes is measured based on the curing periods, such as 7, 14, and 28 days. As shown in Table 10 the maximum compressive strength is 64.80 MPa obtained after the 28 days of curing by the 4M10E mix. Conversely, the minimum compressive strength of 37.10 MPa was achieved by 25E mix after seven days of curing.

Table 10. Compressive strength

Mix ID	Compressive Strength (MPa)		
	7days	14days	28days
CC	50.30	52.6	61.40
5E	50.80	51.73	61.52
10E	50.96	54.42	62.56
15E	48.10	51.84	56.98
20E	42.15	47.46	53.29
25E	37.10	40.56	43.05
2M5E	50.96	52.86	61.90
2M10E	51.85	54.50	63.25
2M15E	48.43	52.10	57.43
2M20E	42.90	48.42	53.60
2M25E	38.20	42.1	47.91
4M5E	51.50	53.4	62.2
4M10E	52.20	56.68	64.80
4M15E	48.5	52.5	58.25
4M20E	43.50	49.6	54.30
4M25E	38.6	42.2	48.25

Figure 1 illustrates how EPS concrete's compressive strength changes with age. In practically all mixtures, the EPS concrete's compressive strength grew steadily over time; however, the pace at which the strength developed was higher at first and slowed down as the EPS content rose. After 7 days of curing, strength comparisons showed that concretes with 4% MMT, the 4M5E, 4M10E, 4M15E, 4M20E, and 4M25E mix shows 1.38%, 2.43%, 0.83%, 3.2% & 4.04% higher strength compared to concretes with 0% MMT the 5E, 10E, 15E, 20E and 25E mix, respectively. The compressive strength of 62.56 MPa and 63.25 MPa after 28 days of curing was achieved by 10E and 2M10E mixes, respectively. MMT may greatly increase compressive strength (up to about 4%), having the same EPS volume content. This implies that MMT may improve the interfacial adhesion between EPS and cement paste as well as EPS dispersion in the cement paste. Consequently, MMT can boost the strength of EPS concrete by substituting certain unique bonding agents at the appropriate content.

4.4. Split Tensile Strength

As per IS 5816-1999, a split tensile strength test was conducted. With 10% EPS replacement, all samples at 7 days, 14 days, and 28 days achieve high tensile strength. Beyond the 10% replacement of EPS, there is a decrease in split tensile strength for all mixes. Thus, it can be shown from the test results that adding montmorillonite to EPS concrete instead of cement increases strength. After 7 days of curing, the mix containing MMT, steel fibre and EPS, 2M5E and 2M10E produced a higher tensile strength of 5.18MPa and 5.43MPa compared to 5E and 10E mix (containing EPS and steel fibre) which has a tensile strength of 5.17 MPa & 5.40 MPa, respectively. The 4M10E mix produced a maximum tensile strength of 6.98 MPa. Table 11 presents the split tensile strength results. The impact of steel fibres and MMT on the split tensile strength of EPS concrete with varying EPS contents is shown in Figure 4. The split tensile strength of EPS concrete was significantly enhanced by steel fibres [23]. The maximum increase in split tensile strength was seen in the EPS concrete with MMT. The 4M5E and 4M10E mix achieves greater strength of 6.52MPa and 6.98MPa after 28 days of curing, which is 2.5% and 9.7% greater than ordinary concrete. Furthermore, EPS concrete split differently from regular concrete in terms of how it failed. Instead of failing suddenly, EPS concrete, particularly those containing steel fibre and MMT, disintegrated gradually.

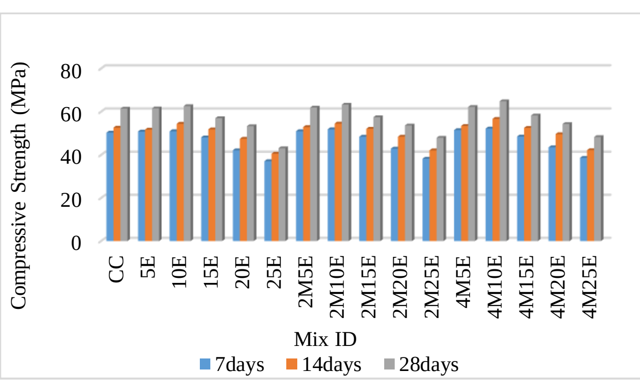

Fig. 4 Variance in values of compressive strength of concrete

Table 11. Split tensile strength

Mix ID	Split Tensile Strength (MPa)		
	7days	14days	28days
CC	5.12	5.29	6.36
5E	5.17	5.36	6.41
10E	5.40	5.79	6.71
15E	4.98	5.40	6.01
20E	4.50	4.94	5.40
25E	3.98	4.35	4.56
2M5E	5.18	5.49	6.45
2M10E	5.43	5.80	6.83
2M15E	5.01	5.52	6.12
2M20E	4.57	5.11	5.46
2M25E	4.10	4.51	4.91
4M5E	5.21	5.56	6.52
4M10E	5.53	6.01	6.98
4M15E	5.02	5.57	6.10
4M20E	4.65	5.18	5.54
4M25E	4.12	4.53	5.07

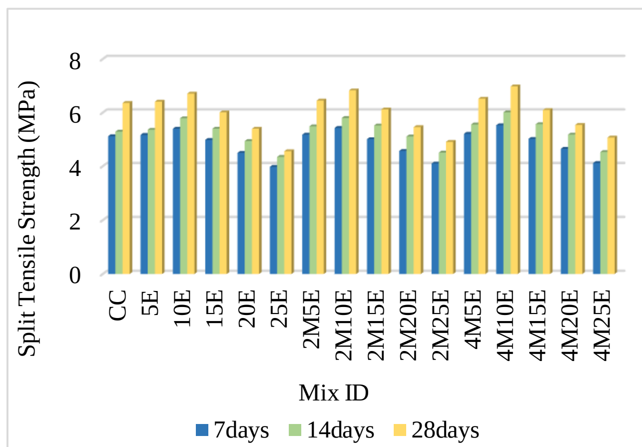

Fig. 5 Variance in values of split tensile strength of concrete

4.5. Flexural Strength

Flexural strength testing was done in compliance with IS 516-1959. The 100 x 100 x 500 mm beam specimens were cast, and after 7, 14, and 28 days, they were tested. As shown in Table 12, the flexural strength of the control concrete mixture was 10.05 MPa, 10.39 MPa, and 12.46 MPa at the age of 7, 14, and 28 days, whereas the other mixtures up to 10% replacement of EPS (10E, 2M10E and 4M10E mixes) achieved higher strength than control mix. Figure 6 illustrates how the bend or flexural strength of each specimen changed according to the various ratios of EPS, MMT, and steel fibre. For example, at 28 days, the flexural strength of regular concrete was around 12.46 MPa, but the addition of 10% EPS, 2% MMT, and 1% steel fibres resulted in a strength of 13.16 MPa. Therefore, compared to regular concrete, the performance of lightweight EPS-based concrete with the specified proportions increased by 5.6%. Due to the ductile nature of steel fibres, which provided resistance against sliding and decreased crack initiation, the lightweight EPS-based concrete's positive bond strength effects were caused, hence boosting the bond strength of the EPS-based concrete mix.Compared to regular concrete, the flexural strength of the 4M10E (4% MMT, 10% EPS, and 1% steel fibres) mix increased to 8.3%. Similar findings were documented: the steel fibres could withstand the elongation and extension of fractures even after flexural cracking [24]. Steel fibres, which function as a bridge before breaking and lessen the breakdown of aggregates in concrete mixtures, have this quality. Flexural strength decreased when EPS replacement in concrete increased beyond 10%. For example, compared to regular concrete, the flexural strength was decreased to 3.4%, 14.3%, and 26.7% with 15%, 20%, and 25% inclusion of EPS in the 4M15E, 4M20E, and 4M25E mix. In conclusion, flexural strength is significantly increased by adding EPS up to 10% in lieu of coarse aggregate, montmorillonite up to 4% in place of cement, and 1% volume fraction of steel fibre.

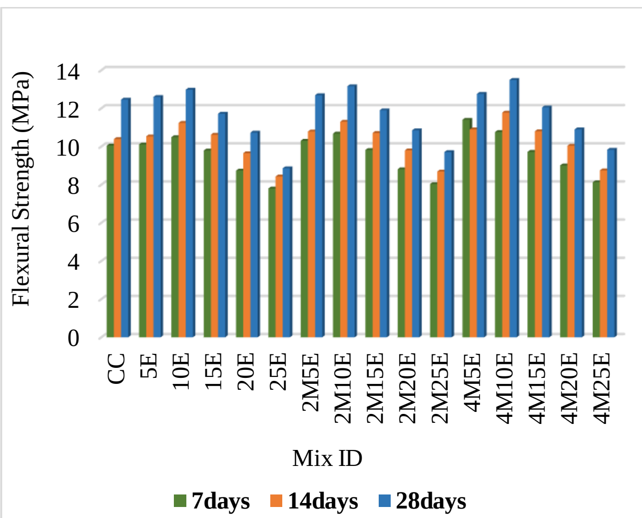

Fig. 6 Flexural strength of concrete

Table 12. Flexural strength

Mix ID	Flexural strength (MPa)		
	7days	14days	28days
CC	10.05	10.39	12.46
5E	10.11	10.53	12.60
10E	10.49	11.24	12.98
15E	9.79	10.62	11.72
20E	8.74	9.65	10.73
25E	7.80	8.43	8.86
2M5E	10.30	10.79	12.69
2M10E	10.68	11.30	13.16
2M15E	9.82	10.71	11.90
2M20E	8.81	9.80	10.85
2M25E	8.03	8.69	9.71
4M5E	11.4	10.90	12.76
4M10E	10.76	11.78	13.49
4M15E	9.72	10.80	12.05
4M20E	9.01	10.04	10.90
4M25E	8.13	8.75	9.83

4.6. Scanning Electron Microscope

After 28 days of curing, SEM was used to analyze the ideal concrete mix for 4M10E. There is not a noticeable space between the steel fibre, EPS, and cement matrix close to the ITZ, as Figure 7 illustrates. Because there is a tight bond between the cement matrix and EPS aggregate, EPS concrete has mechanical properties that are notably superior to those of CC. After steel fibre is combined with concrete, its surface becomes more covered in thin strips, which helps the hydration crystals form and adhere to one another. Hydrated crystals that have thickened and clustered are affixed to the surface's steel fibre and cement matrix. The reason for the enhanced mechanical properties might be attributed to the more hydration crystals visible on the steel fibre surface in the SEM micrographs.

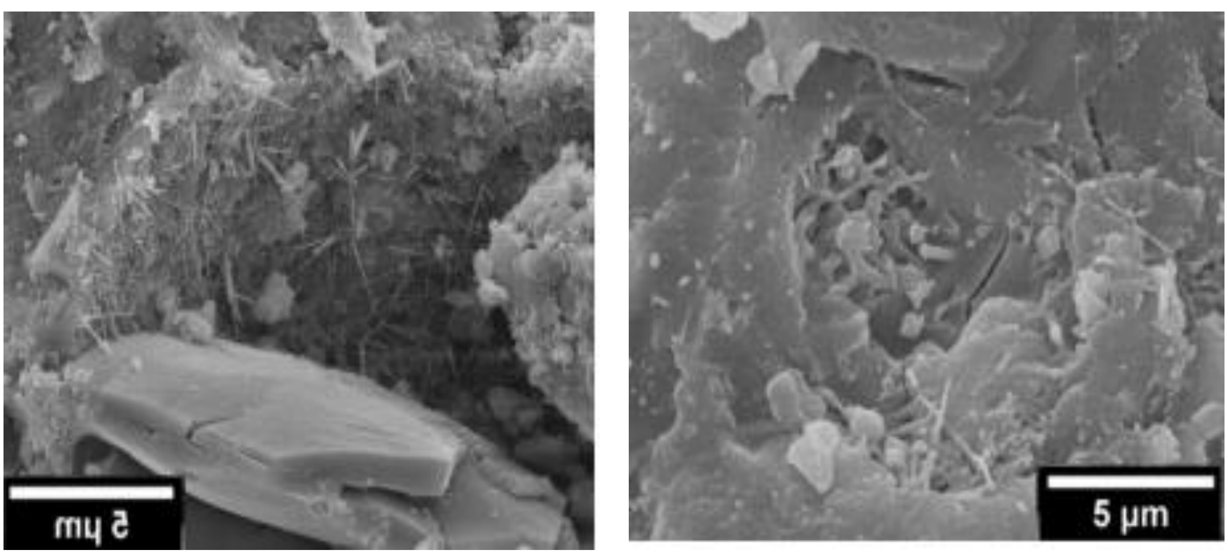

Fig. 7 SEM images of LWC

These crystals strengthen the bond between the steel fibre and the cement matrix at the interface. Figure 7 illustrates the formation of ettringite and Calcium Silicate Hydrate (C-S-H). Because of this, there were fewer pore spaces on LWC mixtures, which explains why the strength qualities were improved. Large EPS cavities may result in a loss of the material's internal integrity, which lowers the compressive strength of further EPS additions.

5. Conclusion

In the present work, the strength parameters of concrete mixtures have been calculated by substituting coarse aggregate with 0%, 5%, 10%, 15%, 20%, and 25% of EPS, 0%, 2%, and 4% of cement with montmorillonite calcined powder and 1% volume fraction of steel fibre. The present study leads to the following conclusions. When cement and coarse aggregate are substituted with EPS and montmorillonite calcined powder, respectively, the workability of concrete rises. The maximum workability was attained by a 25E mix with a slump value of 98mm. The maximum compressive strength after 7, 14 and 28 days of all the mixed combinations was found to be 52.20 MPa, 56.68 MPa, and 64.80 MPa, respectively, when coarse aggregate was replaced with 10% EPS and cement with 4% montmorillonite calcined powder. The maximum split tensile strength for 7 days, 14 days, and 28 days of all the mixed combinations is found to be 5.53 MPa, 6.01 MPa, and 6.98 MPa, respectively, when coarse aggregate was replaced with 10% EPS and cement with 4% montmorillonite calcined powder.

The maximum flexural strength for 7 days, 14 days, and 28 days of all the mixed combinations is found to be 10.76 MPa, 11.78 MPa, and 13.49 MPa, respectively when coarse aggregate was replaced with 10% EPS and cement with 4% montmorillonite calcined powder. It was observed that with the increase in the variation in the replacement, there was a great reduction in the weight of concrete, and the maximum was attained when coarse aggregate was replaced with 25% EPS and cement with 0% montmorillonite calcined powder and was attained 8.81% less than normal weight of concrete.

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