Multifunctional Concrete using Photo catalyst and Fully Replacing Coarse Aggregate with Crushed Styrofoam

Komarina Dileep Chowdary[1], Grandhi Gopal Guptha[2], Karni Dharani[3], Nakka Santosh Kumar[4], Vechalapu Paavana Sai Lakshmi[5]

[1]Assistant Professor, Dept. of Civil Engineering, Sanketika Vidya Parishad Engineering College, VSP, India
[2]B.tech graduate student, Dept. of Civil Engineering, Sanketika Vidya Parishad Engineering College, VSP, India
[3]B.tech graduate student, Dept. of Civil Engineering, Sanketika Vidya Parishad Engineering College, VSP, India
[4]B.tech graduate student, Dept. of Civil Engineering, Sanketika Vidya Parishad Engineering College, VSP, India
[5]B.tech graduate student, Dept. of Civil Engineering, Sanketika Vidya Parishad Engineering College, VSP, India

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Abstract - *Concrete is one of the most widely used construction materials, but its production consumes large amounts of natural resources and contributes to environmental problems. At the same time, waste materials like Expanded Polystyrene (EPS), or Styrofoam, create serious disposal challenges because they do not decompose easily. This project aims to address both issues by developing a sustainable, multifunctional lightweight concrete using recycled Styrofoam and photo catalyst materials.*

In this study, crushed EPS is used as a partial replacement for coarse aggregate, making the concrete lighter and improving its thermal and acoustic insulation properties. Additionally, titanium dioxide (TiO_2) nanoparticles are incorporated into the concrete as a photo catalyst. These particles give the material self-cleaning and air-purifying abilities. When exposed to sunlight, especially ultraviolet (UV) rays, TiO_2 reacts with oxygen and moisture in the air to break down harmful pollutants such as nitrogen oxides (NOx) and volatile organic compounds (VOCs), converting them into less harmful substances that can be washed away by rain.

The combination of EPS and photo catalyst materials results in a concrete that is not only lightweight but also environmentally beneficial. While EPS helps reduce the overall density and improves insulation, TiO_2 enhances the surface functionality of the concrete by actively reducing air pollution.

This research highlights how innovative use of waste materials and advanced technologies can improve the performance of construction materials. Overall, the study demonstrates that multifunctional concrete can support sustainable construction by reducing environmental impact, improving energy efficiency, and contributing to cleaner air in urban areas.

***Key Words*: Lightweight (EPS) Concrete, Sustainable Construction, Titanium Dioxide (TiO_2), Self-cleaning (Photo catalyst) Concrete, Air Purification, Waste Utilization, Multifunctional Concrete, Thermal Insulation**

1. INTRODUCTION

Concrete is one of the most commonly used construction materials because of its strength, durability, and versatility. However, its production consumes large amounts of natural resources and contributes to environmental issues like carbon emissions. At the same time, non-biodegradable waste such as Styrofoam (Expanded Polystyrene – EPS) creates serious disposal problems. To address these challenges, this study explores the development of multifunctional concrete using recycled Styrofoam and photo catalyst materials.

The concept of multifunctional concrete goes beyond traditional strength by adding properties like lightweight performance, thermal insulation, and pollution reduction. In this study, crushed Styrofoam is used as a replacement for coarse aggregates, significantly reducing the weight of concrete while improving thermal and sound insulation. Additionally, titanium dioxide (TiO_2) is incorporated as a photo catalyst, enabling the concrete to break down harmful air pollutants such as nitrogen oxides (NOx) when exposed to sunlight. This also provides self-cleaning, antibacterial, and aesthetic durability benefits.

The main objectives of the study are to develop sustainable concrete, reduce self-weight, utilize waste materials, and evaluate mechanical and functional properties such as compressive strength, workability, and air-purifying ability. The use of Styrofoam promotes waste management, while TiO_2 enhances environmental performance.

The scope of the study focuses on laboratory-scale evaluation of concrete properties with different EPS proportions to determine the optimal mix. Although large-scale applications are not included, the research highlights the potential of this material for lightweight structures, partition walls, and eco-friendly construction solutions. r.

1.1 Objectives of the Study

- To develop multifunctional concrete using photo catalyst materials and Expanded Polystyrene (EPS).

- To study the feasibility of using waste Styrofoam in concrete.
- To reduce the self-weight of concrete by replacing natural coarse aggregates with EPS.
- To evaluate mechanical properties such as compressive strength and workability.
- To analyze photo catalytic properties like air purification and self-cleaning ability.
- To promote sustainable construction through waste utilization and reduced resource consumption.

1.2 Objectives of Additional Materials

Photo catalyst (TiO_2):

- To reduce harmful air pollutants (air purification).
- To provide self-cleaning properties.
- To offer antibacterial and antifungal effects.
- To improve aesthetic durability of concrete surfaces.

Styrofoam (EPS):

- To produce lightweight concrete.
- To enhance thermal insulation.
- To improve sound insulation/absorption.
- To support waste management by recycling plastic materials.

Combined Objective:

To develop a sustainable, lightweight, and eco-friendly concrete with insulation and air-purifying capabilities.

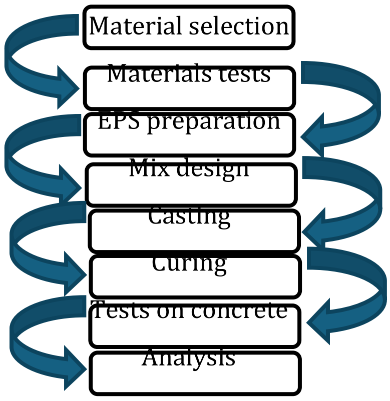
1.3 Scope of the Study

- To develop and test multifunctional concrete using EPS and photo catalyst materials.
- To study physical and mechanical properties such as density, workability, and compressive strength.
- To determine the optimum percentage of EPS replacement.
- To evaluate self-cleaning and air-purifying performance of the concrete.
- To promote sustainable construction using waste materials.
- The study is limited to laboratory-scale testing and does not include large-scale structural applications.

1.3 Problem Statement

- Excessive use of natural aggregates in construction leads to resource depletion and environmental degradation.
- Disposal of non-biodegradable plastic waste like EPS (Styrofoam) is a growing environmental concern.
- Conventional concrete lacks environmental benefits such as pollution reduction and self-cleaning properties.
- There is a need for innovative, sustainable construction materials with added functional benefits.
- The project aims to develop multifunctional concrete using crushed EPS as partial aggregate replacement and incorporating photo catalysts for improved environmental performance.

2. METHODOLOGY



2.1 Materials used and their properties

Cement

Cement is a binding material, used for construction that sets, hardens, and adheres to other materials to bind them together. Ordinary Portland cement (OPC) of 53 grade, of JK Super (Build strong) brand available in local market is used in the investigation. The cement used for all tests is from the same batch.

Table I: Test results on cement

S.no	Properties	Test results observed
1.	Fineness of cement	9 %
2.	Standard Consistency	30%

Fig. 2: Fine aggregate

Fig. 1: Cement

Fine Aggregate

Fine aggregate (commonly referred to as sand) is a critical component of concrete and mortar, typically consisting of granular materials that pass through a 4.75 mm sieve and are retained on a 75 µm sieve. The used fine aggregate is river sand.

Table II: Test results on fine aggregate

S.no	Properties	Test results observed
1.	Fineness Modulus	2.2
2.	Zone of sand	Zone III
3.	Specific Gravity	2.65
4.	Bulk Density	1450 kg/m^3
5.	Moisture content	2.04%
6.	Bulking of Sand	20 %
7.	Silt content	0 %

Coarse Aggregate

Coarse aggregate is a foundational component of concrete which consists of large-sized particles retained on a 4.75 mm sieve, typically ranging up to 37.5 mm in diameter, though sizes can go up to 75 mm for mass concrete. Well graded coarse aggregate of 10 and 20 mm are used.

Fig. 3: 20mm coarse aggregate

Fig. 4: 10mm coarse aggregate

Table III: Test results on coarse aggregate

S.no	Properties	Test results observed
1.	Specific Gravity	2.72
2.	Bulk Density	1623.75 kg/m^3
3.	Flakiness index	11.7 %
4.	Elongation index	8.43 %
5.	Combine index	20.13 %
6.	Aggregate Impact Value	5.7 %

Crushed Styrofoam (EPS)

Crushed Expanded Polystyrene (EPS) or Styrofoam, particularly in the 2–5 mm size range, is used in concrete as a lightweight aggregate to produce Expanded Polystyrene Concrete (EPS Concrete).

Fig. 5: Crushed Styrofoam

Table IV: Test results on Crushed Styrofoam

S.no	Properties	Test results observed
1.	Bulk Density	21 kg/m^3

Titanium Dioxide (TiO_2 – Anatase)

Anatase Titanium Dioxide (TiO_2) is widely used in concrete as a photo catalytic additive, typically at 0.5%–5% by weight of cement, to impart self-cleaning (decolourization of organics) and smog-abating (reduction) properties. It improves compressive/flexural strength and durability, with 2%–3% deemed optimal for balancing performance with cost.

Fig. 6: Titanium Dioxide

Fig. 7: Polycarboxylate ether

Super plasticizer (Polycarboxylate ether (PCE))

Polycarboxylate ether (PCE) super plasticizer is a high-performance, water-reducing, and eco-friendly concrete admixture that drastically reduces water content (up to 30-40%) while enhancing flow ability, strength, and durability.

2.2 Preparation of Crushed Styrofoam

Waste Styrofoam was crushed into 2–5 mm particles, washed, and lightly pre-wetted to minimize water absorption and floating during mixing.

Fig 8: Waste Styrofoam blocks

Fig 9: Simplifying Styrofoam blocks Into Small pieces

Fig 10: Crushed/Shredded Styrofoam

Fig 11: Sieving through 5mm sieve

2.3 Mix Design Proportioning

The concrete mix was designed for M20 and M25 grade as per IS 10262:2019 and IS 456: 2000.

- Coarse aggregate was fully replaced by crushed Styrofoam by volume.
- Water–cement ratio was maintained less than 0.50.
- TiO_2 was added at 5% of cement content and Super plasticizer of 1% of cement was used to improve workability.

Table V: Test results on Crushed Styrofoam

Water–cement ratio used is 0.40		
S.no	Material	Quantity for $1m^3$
1.	OPC 53 Cement	450 kg
2.	Fine aggregate	955 kg
3.	Crushed EPS	6.3 kg
4.	Water	180 L
5.	TiO_2	22.5 kg
6.	Super plasticizer	4.5 kg
Designed M20 mix ratio = **1 : 2.12 : 0.014**		

Table VI: Test results on Crushed Styrofoam

Water–cement ratio used is 0.40		
S.no	Material	Quantity for $1m^3$
1.	OPC 53 Cement	400 kg
2.	Fine aggregate	712 kg
3.	Crushed EPS	8.77 kg
4.	Water	180 L
5.	TiO_2	20 kg
6.	Super plasticizer	4 kg
Designed M25 mix ratio = **1 : 1.78 : 0.022**		

2.7 Mixing, Casting and Curing

Dry Mixing

- Mix cement and sand for 2-5 min
- Add TiO_2 powder and mix properly to ensure even distribution.

- Add crushed Styrofoam slowly to the mix and mix carefully to avoid segregation (Styrofoam is very lightweight).

Fig 12: Wet mixing

Fig 13: Dry mixing

Wet Mixing

- Add 70 % of water gradually (water–cement ratio ~0.4–0.5).
- Mix it for 3–4 minutes
- Add super plasticizer to the remaining 30% water
- Add super plasticizer mixed water to the mix
- Mix until it is uniform, workable mix is obtained.
- Avoid over mixing to prevent floating of Styrofoam.

Casting Process

➢ Preparation of Moulds
- Use standard moulds (cube: 150×150×150 mm, cylinder, or prism).
- Clean and apply oil to the inner surface to prevent sticking.

➢ Placing of Concrete
- Pour the concrete mix into moulds in 3 layers.

➢ Compaction
- Use light tamping or hand compaction.
- Give 25-35 blows for each layer.
- Avoid heavy vibration because:

✓ Styrofoam may float to the top
✓ Segregation may occur

➢ Levelling and Finishing
- Level the surface using a trowel.
- Ensure a smooth and even finish.
-

Fig 14: Casted cubes and cylinders

Labelling each specimen

Each cube and cylinder was clearly labelled with a unique ID indicating:

- Mix type (control, percentage, or additive)
- Date of casting

Initial Setting

- Keep the moulds undisturbed for 24 hours at room temperature.
- Cover the surface with plastic sheets or wet cloth to prevent moisture loss.

De-moulding

- After 24 hours, carefully remove specimens from moulds.
- Handle gently since early strength may be low due to Styrofoam content.

Curing Process

➢ Method: Water Curing
- Immerse the specimens in Water Tank
- Place specimens in clean water tanks.
- Maintain temperature around 20–27°C.

➢ Curing Duration: Immerse the specimens for a curing period of:
- 7 days (early strength), 14 days, 21 days, and 28 days (final strength)

Fig 15: Cured cubes and cylinders

Precautions

✓ Do not use heavy vibration
✓ Use uniform size of crushed Styrofoam
✓ Maintain proper water-cement ratio
✓ Handle specimens carefully during de-moulding
✓ Ensure proper curing to improve strength

2.8 Thermal Insulation of this Concrete

✓ This concrete mix has improved thermal insulation mainly due to the use of EPS (Expanded Polystyrene) and the removal of coarse aggregates.

✓ EPS plays a key role even in small quantities because it is about 98% air. This air content disrupts heat flow, making the material a good insulator. In contrast, cement and sand conduct heat much more easily.

✓ The absence of coarse aggregates also helps. In normal concrete, these aggregates act as thermal bridges, allowing heat to pass through quickly. Removing them reduces heat transfer.

✓ Lower density is another important factor. Lightweight concrete naturally provides better insulation because it contains more air and less solid material for heat conduction.

✓ Smaller EPS particles (2–5 mm) ensure uniform distribution, creating evenly spaced air voids. This leads to consistent insulation performance throughout the concrete.

✓ Thermal insulation depends on thermal conductivity (k value).

Lower k value → higher insulation
Higher k value → Lower insulation

- ✓ Material - k (W/mK)
  Normal concrete - 1.5–1.8
  Our cube - 0.6–1.0
  EPS - 0.03–0.04
- ✓ Conclusion
  By replacing about 40–50% of the volume with 2–5 mm crushed EPS (with a very low density of 21 kg/m^3), the concrete traps more air and reduces heat flow. As a result, it offers much better thermal insulation compared to conventional concrete.

2.9 Tests done on Concrete

Laboratory tests were carried out the prepared concrete samples. The following tests were conducted:

1. Tests on fresh concrete-
   - ✓ Workability test (Slump cone test)
   - ✓ Density / Unit weight test
2. Tests on harden concrete-
   - ✓ Compressive strength test at 7, 14, 21 and 28 days
   - ✓ Split tensile strength test at 7, 14, 21 and 28 days
   - ✓ Water absorption after 28 days
   - ✓ Self-cleaning and photo catalytic performance under sunlight using methylene blue

3. CONCRETE TEST ANALYSIS AND EVALUATION OF RESULTS

Test results were analysed and compared with conventional M20 and M25 concrete to evaluate the effect of TiO_2 addition and full EPS replacement on strength and multifunctional performance. The results were presented using tables, pictures and graphs. Conclusions and recommendations were given at the end of the project.

3.1 Slump cone Test (Workability):

Table -VII: Slump cone Test (Workability) values

S. no	Mix Type	Slump Value (in mm)
1.	M20 conventional concrete mix	25 mm
2.	M20 multifunctional concrete mix	30 mm
3.	M25 conventional concrete mix	60 mm
4.	M25 multifunctional concrete mix	75 mm

S. no	**Mix Type**	**Density of concrete (in kg/m3)**
1.	M20 conventional concrete mix	2587.3
2.	M20 multifunctional concrete mix	1782
3.	M25 conventional concrete mix	2465.7
4.	M25 multifunctional concrete mix	1553

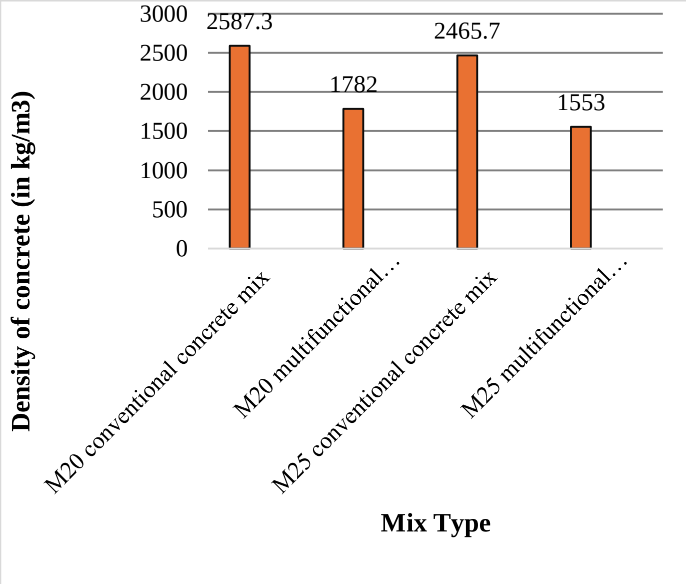


Chart -2: Unit weight test results

3.3 Compressive Strength Test (28 Days):

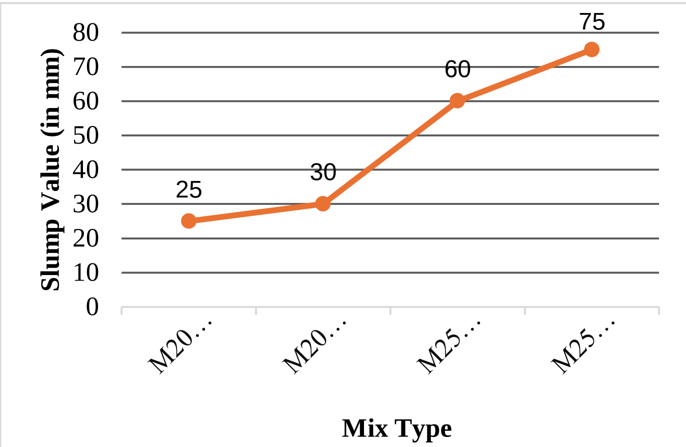


Table -XI: Compressive Strength Test values

Mix Type	Compressive Strength (in N/mm² or MPa)			
	7 DAYS	14 DAYS	21 DAYS	28 DAYS
M20 conventional concrete mix	16.74 N/mm^2	20.43 N/mm^2	22.07 N/mm^2	22.67 N/mm^2
M20 multifunctional concrete mix	5.34 N/mm^2	6.67 N/mm^2	8.22 N/mm^2	9 N/mm^2
M25 conventional concrete mix	12.89 N/mm^2	24.45 N/mm^2	27.12 N/mm^2	28.8 N/mm^2
M25 multifunctional concrete mix	4.9 N/mm^2	5.8 N/mm^2	6.67 N/mm^2	8 N/mm^2

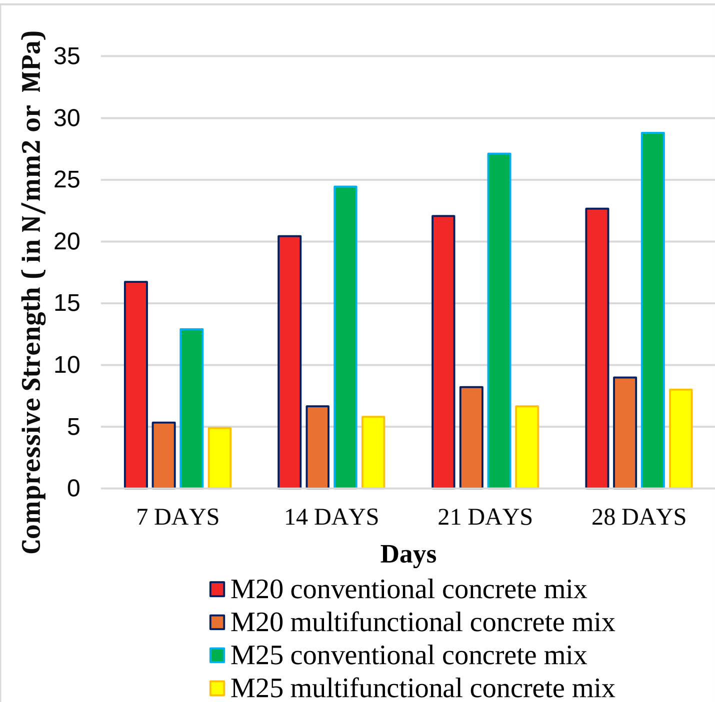


Chart -3: Compressive Strength Test results

3.4 Split Tensile Strength Test (28 Days):

Table -X: Split Tensile Strength Test values

Mix Type	Split Tensile Strength (in N/mm² or MPa)			
	7 DAYS	14 DAYS	21 DAYS	28 DAYS
M20 conventional concrete mix	0.70 N/mm^2	0.99 N/mm^2	1.34 N/mm^2	1.55 N/mm^2
M20 multifunctional concrete mix	0.28 N/mm^2	0.43 N/mm^2	0.7 N/mm^2	0.7 N/mm^2
M25 conventional concrete mix	1.27 N/mm^2	1.55 N/mm^2	2.12 N/mm^2	2.4 N/mm^2
M25 multifunctional concrete mix	0.28 N/mm^2	0.57 N/mm^2	0.57 N/mm^2	0.7 N/mm^2

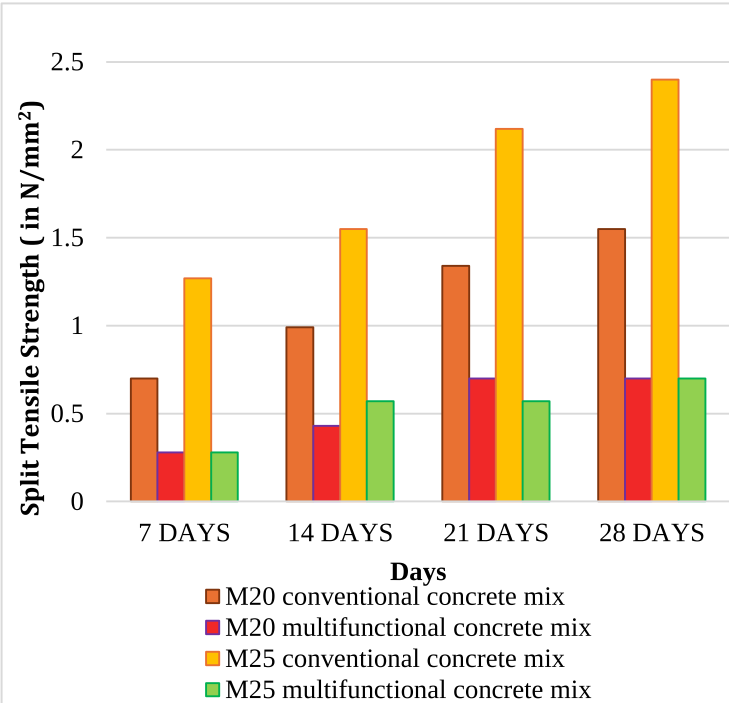
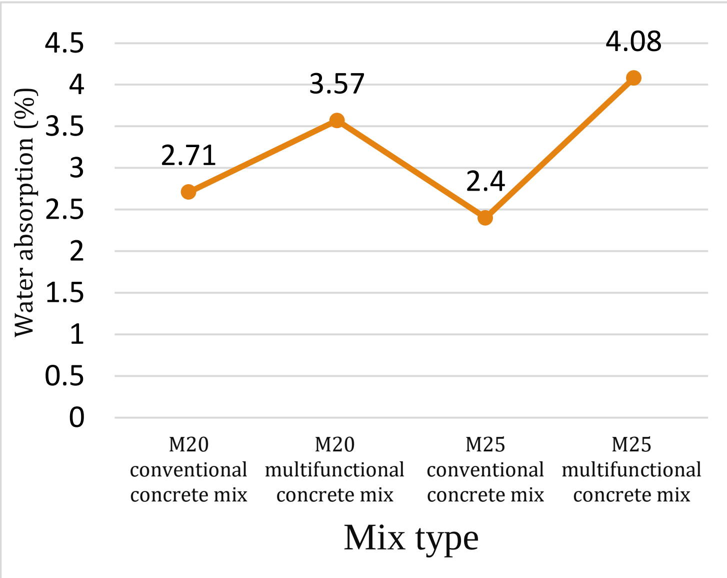


Chart -4: Split Tensile Strength Test results

3.5 Water absorption test:

Table -XI: Water absorption Test values

Mix Type	Water absorption (In %)
M20 conventional concrete mix	2.71
M20 multifunctional concrete mix	3.57
M25 conventional concrete mix	2.4
M25 multifunctional concrete mix	4.08



Method 1 -

- Prepared a dye solution of light blue color by adding Methylene Blue to water in a bucket or Transparent glass beakers.
- Kept the concrete cube specimen in this solution.
- The bucket is then kept in sunlight or UV light

Method 2 -

- Poured a few drops of Methylene Blue solution onto the concrete specimen surface
- Keep in dark for 30 minutes (adsorption stage)
- Expose the concrete cube to sunlight or UV light

Then observe

- Take photos at regular intervals (0, 1, 2, 3, 4 hrs.)
- Compare color fading visually.

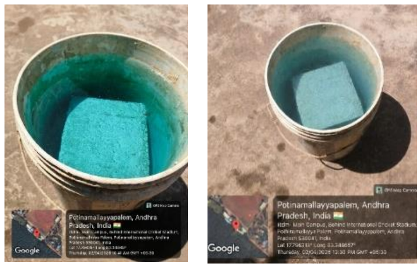


Fig 16: Colour fading in water observation

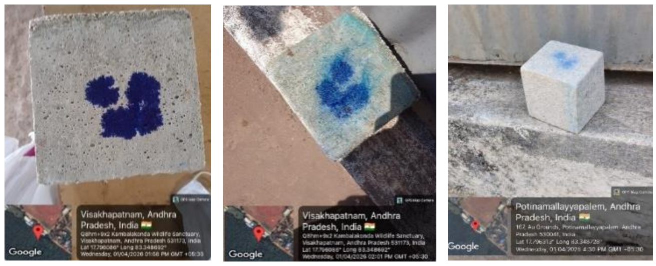


Fig 17: Colour fading on cube observation

4. CONCLUSIONS

- This study explores how waste EPS (expanded polystyrene) can be used in concrete to make it lighter and more environmentally friendly, while also adding photo catalytic benefits.
- The results show that replacing traditional materials with crushed EPS significantly reduces the density and overall weight of concrete, making it suitable for lightweight applications.
- The workability of the concrete improves slightly compared to conventional mixes. However, because EPS is lightweight, the density drops quite a bit—about 31% for M20 and 37% for M25 mixes.
- This reduction in weight is useful, but it also leads to lower compressive and tensile strength. Even so, the strength levels are still acceptable for non-structural uses.
- Water absorption increases slightly, but remains within acceptable limits (below 5%). In terms of cost, M20 multifunctional concrete becomes much more expensive, while M25 shows only a small increase, making M25 the more practical option.
- Photo-catalyst test confirms strong photo catalytic activity. The specimen effectively degraded the surface pollutants within a 4–10 hour, proving its potential for "self-cleaning" applications in real-world environments.
- Overall, while using 100% EPS reduces strength, adjusting the percentage can help strike a balance between strength, reduced weight, and sustainability.

- The study highlights how recycled materials like EPS can contribute to greener, more innovative construction practices.

5. FUTURE SCOPE

The present study provides a foundation for further research on multifunctional concrete. The following areas can be explored in the future:

- Investigation of different percentages of EPS replacement to determine the optimum proportion that provides both strength and lightweight properties.
- Study of additional mechanical properties such as tensile strength, flexural strength, and durability of EPS concrete.
- Evaluation of long-term performance and durability under different environmental conditions.
- Use of other waste materials along with EPS to improve the sustainability of concrete.
- Detailed analysis of photo catalytic efficiency in reducing air pollutants in real environmental conditions.
- Application of multifunctional concrete in practical construction projects such as non-load bearing walls, panels, pavements, and insulation structures.
- Development of improved mix designs to enhance the strength and durability of EPS-based concrete.
- Further research in these areas can help in developing more efficient, durable, and environmentally friendly construction materials for future infrastructure development.

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