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Experimental Studies on the Strength Enhancement of Concrete Incorporating Diatomaceous Earth, Expanded Perlite and Polytencrete NGT Admixture

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Abstract: The study investigated the effect of Diatomaceous Earth (DE), Expanded Perlite (EP), and Polytencrete NGT on the strength of M30 grade concrete. Cement was partially replaced with DE at 10% and 15%, while fine aggregate was replaced with 15% EP, and Polytencrete NGT was added at 0.3% by weight of cement. Two mixes, M1 (10% DE + 15% EP) and M2 (15% DE + 15% EP), were compared with normal concrete. Tests were conducted for workability, compressive strength, and split tensile strength. The results showed that M1 achieved the highest improvement in both compressive and tensile strength compared to the normal mix.

Key Words: Diatomaceous earth, Expanded perlite, Polytencrete NGT admixture, compressive strength, split tensile strength.

I. INTRODUCTION

Concrete stands as the foundation of modern construction, valued for its adaptability, strength, and ability to take on any desired shape or form. It is the most widely used construction material in the world, second only to water in terms of consumption, owing to its indispensable role in infrastructure, housing, and industrial development. However, conventional concrete faces growing challenges linked to environmental impact, depletion of natural resources, and the demand for enhanced performance in modern structural applications. The primary binding material, Ordinary Portland Cement (OPC), is a significant source of carbon dioxide emissions, primarily generated during limestone calcination and high-temperature kiln processes. The cement industry uses a lot of energy and is one of the biggest sources of carbon dioxide emissions globally, contributing about 7–8 percent of all emissions. The growing concern over the environmental impact of cement and natural river sand has led to research on sustainable alternatives in concrete production. Supplementary Cementitious Materials (SCMs) help reduce cement use, while alternatives to river sand help protect ecosystems. Diatomaceous Earth (DE), formed from fossilized diatoms, is rich in silica that reacts with calcium hydroxide during cement hydration to form calcium silicate hydrate (C-S-H) gel, improving strength and durability while reducing cement usage. Expanded Perlite (EP), produced by heating natural perlite, offers a lightweight, porous structure that enhances strength and reduces water penetration when used in place of sand. Additionally, Polytencrete NGT, a PCE-based admixture, improves concrete workability and flow without extra water, resulting in a smoother and stronger mix. Together, these materials contribute to more eco-friendly, durable, and efficient concrete for sustainable construction.

II. LITERATURE REVIEW

1) Leandro J. R. Magalhaes, Débora Macanjo Ferreira1, Ana Belén Ramos-Gavilan (2024) : This study investigates the use of Spent Calcined Diatomaceous Earth (SCDE) as a partial replacement for cement in M20 grade concrete, with replacement levels of 0%, 5%, 7.5%, and 10%. The water–cement ratio was kept constant at 0.62, and tests for compressive strength, water absorption, and density were performed at both 7 and 28 days to determine the optimum level of SCDE replacement. At 10% SCDE substitution, the 28-day compressive strength showed a 1.38% increase over the control mix (21.9 MPa vs. 21.6 MPa), attributed to the filler effect and improved hydration from SCDE's fine particles. The density reduced by 1.85% (from 2317 to 2274 kg/m³), resulting in a lighter concrete due to SCDE's lower particle density, while water absorption decreased by 1.78%, indicating a denser and less permeable microstructure. The study concluded that 10% SCDE replacement achieved a balance between strength and weight reduction, showing slower early strength gain but improved long-term performance compared to conventional concrete.

2) Jiaqi Li, Wenxin Zhang, Chen Li, Paulo J.M. Monteiro (2019): This study analyses the effect of replacing Portland cement (PC) with diatomaceous earth (DE) in concrete mixes at 10%, 20%, and 30% replacement levels. The mix was prepared with a water–cement ratio of 0.48, and a PCE-based superplasticizer (BASF) was used to maintain a slump of approximately 100 mm. The study aimed to reduce cement consumption, thereby lowering construction costs, global warming potential, energy use, and air pollutant emissions through a sustainable mix design. The results showed that all DE-containing concretes achieved 3–7 MPa higher compressive strength at 7 days and 5–15 MPa higher strength at 28 days compared to the control mix, due to enhanced pozzolanic activity and continuous strength gain over time. The workability also improved, as the slump of DE mixes was 3–19% higher than normal concrete, attributed to the high porosity and low reactivity of DE. Overall, concretes with 10–30% DE replacement achieved 15–38% higher strength than conventional mixes, proving that DE enhances strength while improving workability and reducing environmental impact.
3) Y. Madhusudhan Reddy, Dr T.Chandra Sekhar Reddy (2020) : This study investigates the use of Diatomaceous Earth (DE) as a partial replacement for cement in concrete to enhance strength and sustainability. Cement was replaced with DE in varying proportions from 0% to 25%, while maintaining a constant water–cement ratio of 0.45. Compressive and split tensile strength tests were conducted at 7 and 28 days, along with SEM and XRD analyses to study the microstructural and chemical changes. The 15% DE mix achieved the highest compressive strength of 46.96 MPa, showing a 19.64% increase compared to normal concrete , and a split tensile strength of 3.84 MPa, representing a 15.66% improvement compared to normal concrete. The strength enhancement was primarily due to the formation of kaolinite and additional calcium silicate hydrate (C–S–H) gel, which refined the microstructure and improved compactness. Beyond 15% replacement, a slight reduction in strength was observed, indicating that 15% is the optimal dosage. Overall, incorporating 15% DE improved both strength and sustainability by reducing cement consumption, cost, and carbon emissions, making it an efficient and eco-friendly alternative for concrete production.
4) V. Khonsari, E. Eslami & Ah. Anvari (2010): This study examines the use of Expanded Perlite (EP) as a partial replacement for coarse aggregate in M40 grade lightweight concrete, aiming to achieve a lighter and more thermally insulating mix. EP was added at 0–40% by weight with a water–cement ratio of 0.35, and 2.5% superplasticizer was used. Compressive and split tensile strengths were tested at 28 days. The 15% EP mix achieved a compressive strength of 37.0 MPa (20.77% lower) and a tensile strength of 1.32 MPa (39.72% lower) than the control. The reduction in strength is attributed to moisture loss and reduced hydration due to EP's high porosity. However, apparent porosity increased by 22.02%, improving insulation potential. Overall, while strength decreased with higher EP content, moderate replacement levels can yield lightweight, energy-efficient concrete suitable for non-structural or moderate-strength applications.
5) Ilker Bekir Topc¸u, Burak Is¸ıkda˘g (2007): This study examines the influence of Expanded Perlite Aggregate (EPA) on concrete properties using two cement types (CEM II 32.5R and CEM I 42.5R), three cement dosages (300, 350, and 400 kg/m³), and replacement levels of 0–60%. The water–cement ratio was kept constant at 0.5, and tests for slump, compressive strength, split tensile strength, and unit weight were performed. The goal was to develop lightweight concrete with reduced dependence on natural aggregates while maintaining acceptable strength. Results showed that unit weight increased with higher cement dosages but decreased due to the EPA's porous structure. Slump values ranged from 100 to 130 mm, decreasing as cement dosage and quality increased. The highest compressive and tensile strengths (37 MPa and 3.5 MPa) were achieved with 400 kg/m³ cement dosage, while higher EPA replacement reduced strength but improved lightweight characteristics. The optimum performance was observed between 15% and 30% EPA replacement, especially with CEM I 42.5R, balancing workability, strength, and density effectively.

III. OBJECTIVES

1) To develop mix designs for concrete incorporating diatomaceous earth and expanded perlite as partial replacements, in reference to a normal concrete mix.
2) To analyse the fresh-state properties and the hardened-state properties of concrete mixes with 10%–15% replacement of diatomaceous earth with cement, 15% replacement of expanded perlite with fine aggregate, and the normal concrete mix, and evaluate the extent of strength enhancement achieved.

IV. METHODOLOGY

A. Materials used

1) Cement

OPC 53 grade (CCI cement) conforming to IS 12269:2013 is used in this study. OPC was selected as the primary binder because of its widespread availability, consistent quality, and suitability for structural-grade concrete. The cement used in the present work was fresh and free from lumps.

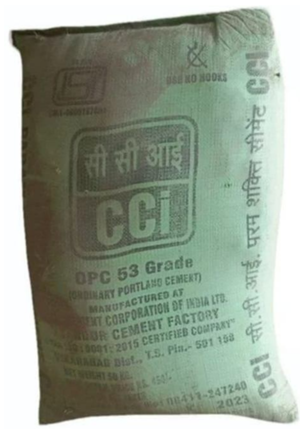

Fig.1 Cement

2) Fine aggregates (FA)

In the present study, fine aggregate used for concrete production consisted primarily of natural river sand that was sourced locally and utilized as the fine aggregate in all concrete mixes. The sand conforms to the grading requirements, with most particles passing through a 9.5 mm sieve, ensuring suitable fineness and uniformity.

Fig.2 Fine Aggregates

3) Coarse Aggregate (CA)

The coarse aggregates used in this study consisted of locally sourced crushed stone with nominal sizes of 20 mm and 12.5 mm, meeting standard grading requirements. Coarse aggregates provide the primary structural framework in concrete.

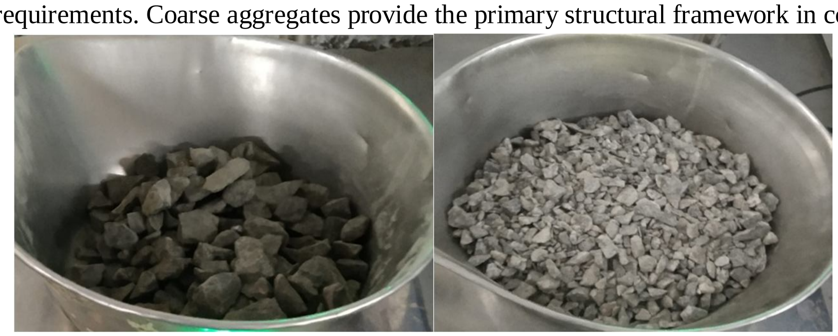

Fig.3 Coarse aggregates of 20mm and 12.5mm

4) Water

Potable tap water was used for the preparation of specimens and for curing specimens.

5) Diatomaceous earth (DE)

Diatomaceous earth is used as a supplementary cementitious material for the replacement levels of 10% and 15%. The properties of diatomaceous earth are given below. Chemical Composition of DE consists of SiO_2CaO, MgO, Al_2O_3, Fe_2O_3, Na_2O

Fig.4 Diatomaceous Earth

Diatomaceous Earth Properties

Property	Value
Appearance	White powder
PH	9
Specific Gravity	2.2
Particle Size	10 – 200 µm

6) Expanded perlite (EP)

The expanded perlite was used as a filler in fine aggregate replacement at 15% by volume of sand. The properties of expanded perlite are given below. Chemical composition of Expanded perlite Consists of Na_2O, MgO, Al_2O, SiO_2, K_2O, CaO

Fig.5 Expanded perlite

Expanded perlite Properties

Property	Value
Grade	SF 2
Colour	White
PH	Neutral
Specific Gravity	2.2
Particle size	0.6 – 3.00 mm

7) Polytencrete NGT superplasticizer

A PCE-based superplasticizer was used at a fixed dosage of 0.3% by weight of cement.

Fig 6. Polytencrete NGT

Properties of Polytencrete NGT

Property	**Value**
Appearance	Dark Brown Liquid
PH	6.5 – 8.5
Dosage	0.3 % by weight of cement
Specific Gravity	1.10

8) Mix design

Mix design is done for M30 grade of concrete, following the standards IS:10262-2019 and IS:456-2000.

For the experiment, cement was partially replaced by diatomaceous earth at replacement levels of 10% and 15% by weight, and sand was partially replaced by expanded perlite at a constant replacement level of 15% and a fixed dosage of 0.3% of Polytencrete NGT superplasticizer. The same batch of materials was consistently used for all mix proportions to maintain uniformity and reliability in results. The mix proportion for 1 m³ of concrete.

%	Cement kg/m^3	DE kg/m^3	FA kg/m^3	EP kg/m^3	CA kg/m^3	Water kg/m^3	Chemical admixture kg/m^3
NC	428.608	-	616.48	-	1071.8	192.39	-
M1	314.21	34.91	569.41	3.188	1134.82	191.837	1.047
M2	309.655	54.645	557.41	3.121	1139.88	191.747	1.047

9) Specimen Preparation

a) Batching and Mixing

The required quantities of cement, diatomaceous earth, expanded perlite, fine aggregate, and coarse aggregate were mixed in a tray until a uniform and consistent blend was obtained. This process ensured that the Diatomaceous Earth and Expanded Perlite were evenly distributed throughout the mix. After achieving a uniform dry blend, water and the Polytencrete NGT admixture were gradually added while mixing continued. The process was maintained until the concrete reached a smooth, cohesive, and workable consistency, free from clumps or segregation. The final mixture displayed a uniform color and texture, indicating thorough and even blending of all components.

Fig.7 Mixing

b) Casting

The cube moulds were cleaned, dried, and lightly oiled to prevent sticking. The concrete mix was poured in three equal layers, each compacted 25 times using a tamping rod. The surface was then leveled with a trowel for a smooth finish. The specimens were left to set for 2–3 hours and later labeled with the mix type and percentage of Diatomaceous Earth.

Fig.8 Casting

c) Curing

All specimens were demoulded after 24 hours, then immediately placed in a water-curing tank containing clean potable water to ensure proper hydration. Curing was carried out for 7 and 28 days to evaluate strength development over time. To evaluate the variation in strength and performance of concrete incorporating diatomaceous earth, expanded perlite, and polytencrete NGT admixture at different curing ages.

Fig.9 Curing

V. TESTING OF SPECIMENS

A. Fresh Properties

1) Slump Test

The workability of the fresh concrete was assessed using the slump cone test as per IS 1199:1959. The slump cone used was 300 mm high, with a 200 mm base and 100 mm top. The concrete mix was filled in four layers, each compacted 25 times with a tamping rod to remove air pockets. After leveling the top, the cone was gently lifted in 5–10 seconds to let the concrete slump naturally. The height difference between the original cone (300 mm) and the slumped concrete was recorded as the slump, indicating the workability and consistency of the mix.

$$\text{Slump (mm)} = H2 - H1$$

Where,

H1 = Height between the handle and the top of the slump cone

H2 = Height between the handle and the top of the concrete

Fig 10. Slump

B. Hardened Properties

1) Compressive Strength

The compressive strength test followed IS 516:1959 guidelines. Cube specimens of 150 mm × 150 mm × 150 mm were tested after curing for 7 and 28 days. Before testing, the cubes were wiped clean and centred carefully in the Compression Testing Machine (CTM) to ensure uniform load distribution during testing. The load was then applied gradually at a constant rate until the cube failed.

The ultimate load at failure was recorded directly from the CTM, and the compressive strength of the specimen was calculated using the relation:

$$\text{Compressive strength } = \frac{\textit{Load Applied}}{\textit{Cross section of the area}} \text{ in N/mm2}$$

Fig.11 Cube Under Compressive Load

2) Split Tensile Strength

The split tensile strength of the concrete specimen was determined as per the procedure given in IS: 5816–1999. Cylindrical specimens of 150 mm diameter and 300 mm height were prepared for each mix and cured for 7 days and 28 days. Before the test, the surface of the cylinders were wiped clean and dried to remove excess moisture. For the split tensile strength test, each cylindrical specimen was positioned horizontally between the steel plates of the CTM, ensuring the load was applied along the diametral plane. The load was gradually increased at a constant rate until the specimen split vertically into two halves, indicating failure due to tensile stress.

$$f_t = \frac{2P}{\pi \, D \, L}$$

Where,

f_t = Split Tensile Strength in N/mm2
P = maximum load at failure in N
D = Diameter of Cylinder in mm
L = Length of the cylinder in mm

Fig. 12 Cylinder Under Tensile Load

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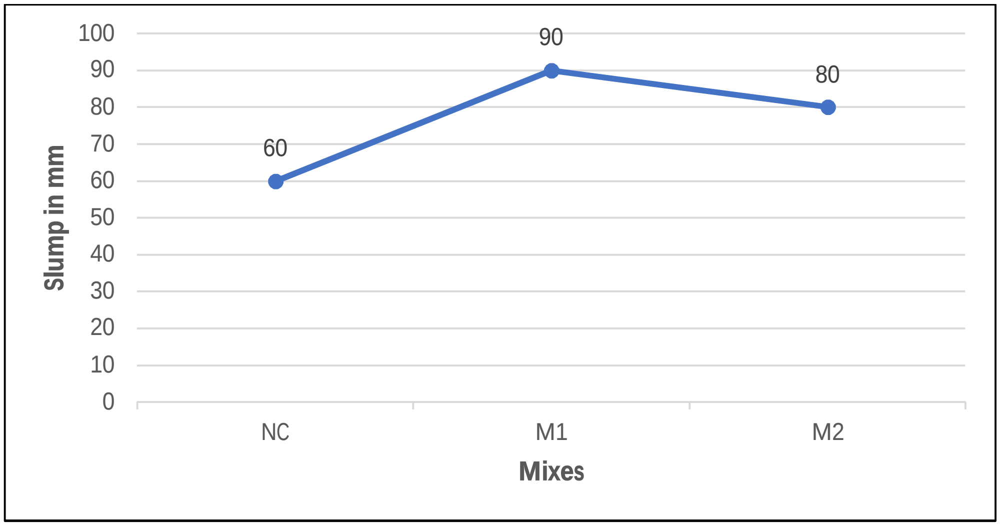
VI. RESULTS AND DISCUSSION

A. Slump test

Mix	Percentage replacement of DE and EP	Superplasticizer	Value (mm)
NC	0 %	0 %	60
M 1	10 % DE and 15 % EP	0.3 %	90
M 2	15 % DE and 15 % EP	0.3 %	80

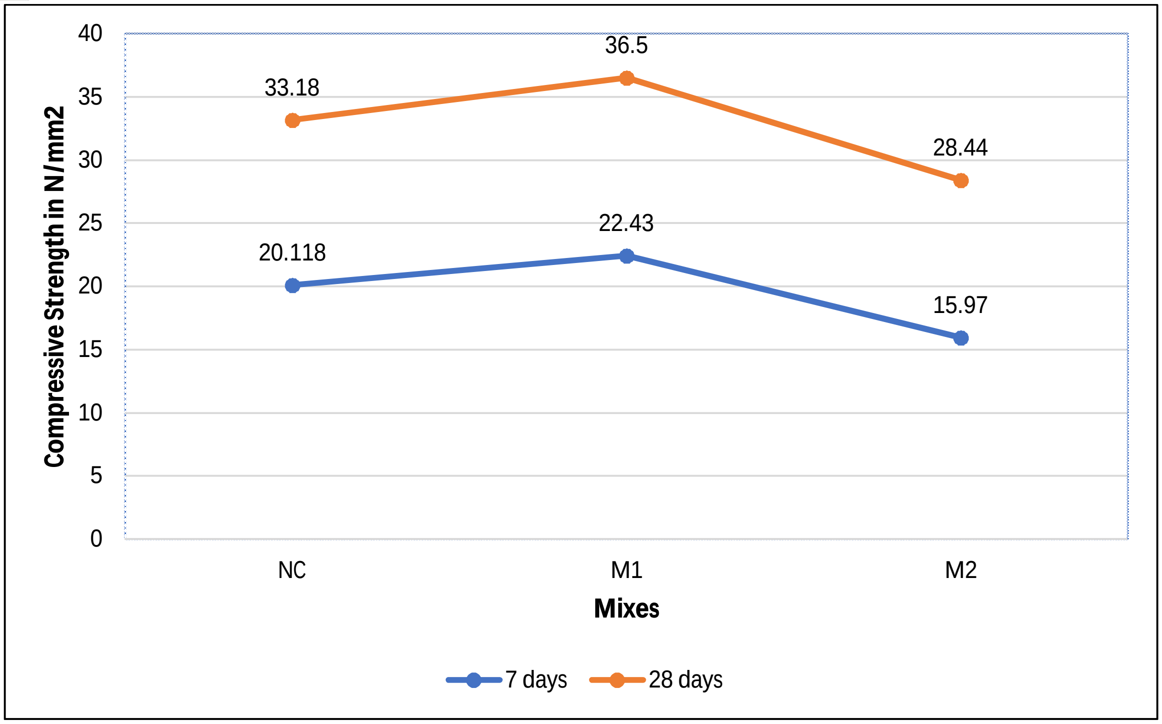


Line Graph Showing Variation of slump with Diatomaceous Earth and Expanded perlite replacement

The slump test results indicated improved workability with the incorporation of Diatomaceous Earth (DE) and Expanded Perlite (EP). The normal mix showed a slump of 60 mm, while M1 and M2 recorded 90 mm and 80 mm, respectively. The increase at M1 is attributed to the fine and porous nature of DE and EP, along with the dispersing effect of the Polytencrete NGT admixture. The slight reduction at M2 suggests higher water demand due to increased fineness, yet the mix maintained good workability without segregation or bleeding.

B. Compressive Strength Test

Mix	Percentage replacement of DE and EP	Curing period	Average Compressive Strength (N/mm2)
NC	0 %	7 days	20.118
		28 days	33.18
M1	10 % DE and 15 % EP	7 days	22.429
		28 days	36.501
M2	15 % DE and 15 % EP	7 days	15.97
		28 days	28.44

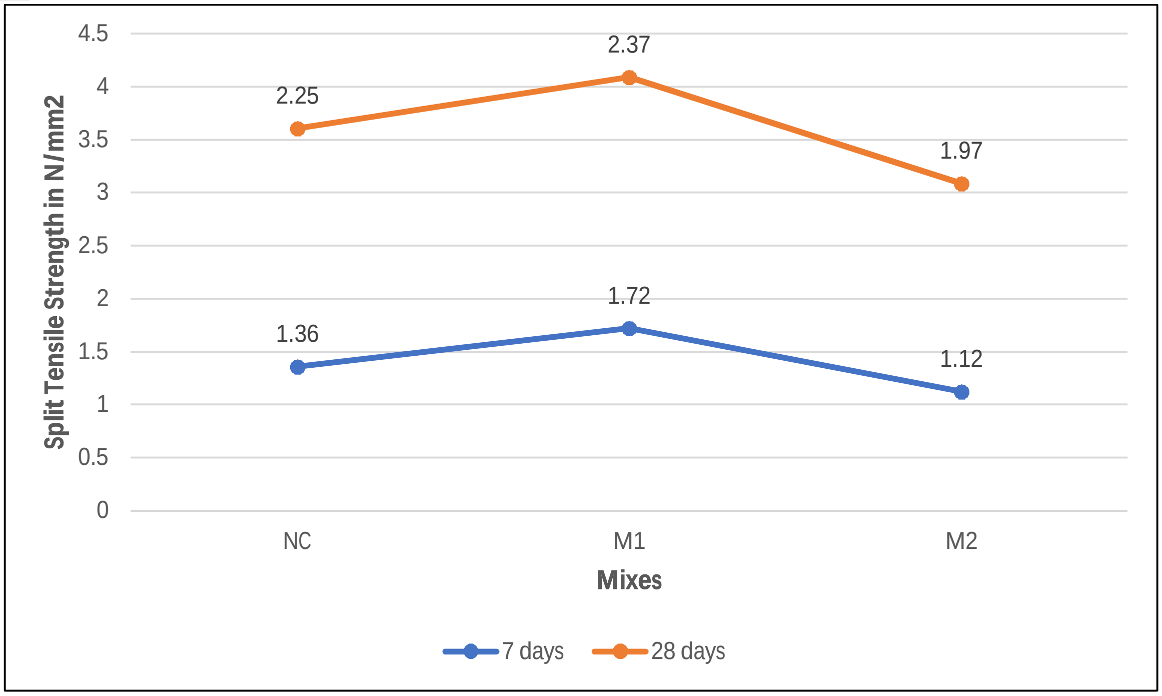


Line Graph Showing Variation of 7-Day and 28-Day Compressive Strength with Diatomaceous Earth and Expanded perlite replacement

The compressive strength results 5 for 7 and 28 days showed that the normal concrete (NC) attained 20.12 N/mm² and 33.18 N/mm², aligning with M30 grade expectations. The M1 mix (10% DE + 15% EP) achieved higher strengths of 22.43 N/mm² and 36.50 N/mm², reflecting a 10–12% improvement over NC. This enhancement is attributed to the pozzolanic activity of Diatomaceous Earth, forming additional C–S–H gel and the internal curing effect of Expanded Perlite, supported by improved dispersion from the Polytencrete NGT admixture. In contrast, M2 (15% DE + 15% EP) showed reduced strengths of 15.97 N/mm² and 28.44 N/mm² due to excessive cement replacement, higher water demand, and weaker interfacial zones. Overall, 10% DE and 15% EP proved to be the optimum combination for enhancing compressive strength.

C. Split Tensile Strength Test

Percentage replacement of DE and EP	Curing period	Average Split Tensile strength (N/mm2)
0 %	7 days	1.36
	28 days	2.25
10 % DE and 15 % EP	7 days	1.72
	28 days	2.37
15 % DE and 15 % EP	7 days	1.12
	28 days	1.97



Line Graph Showing Variation of 7-Day and 28-Day Split tensile Strength with Diatomaceous Earth and Expanded perlite replacement

The tensile strength results followed the same trend as compressive strength. The control mix achieved 1.36 N/mm² and 2.25 N/mm² at 7 and 28 days, respectively. The mix with 10% DE + 15% EP (M1) showed improved strengths of 1.72 N/mm² and 2.37 N/mm², attributed to ITZ refinement, better paste–aggregate bonding, and stress redistribution by perlite. In contrast, 15% DE + 15% EP (M2) showed reduced strengths (1.12 N/mm², 1.97 N/mm²) due to excess fines and higher water demand. Hence, the 10% DE + 15% EP mix was found to be optimum.

D. One way ANOVA

One-way ANOVA was done between the 7- and 28-days strengths of Compressive strength and tensile strength values, after the analysis it was found that there is a statistically significant differences ($p < 0.05$) in compressive and tensile strengths among NC, M1, and M2, indicating that the variations were due to the incorporation of DE, EP, and Polytencrete NGT rather than random error. The results show that M1 had a statistically significant improvement, which is thanks to the combined effects of pozzolanic and filler properties.

VII. CONCLUSION

1) Adding Diatomaceous Earth (DE) and Expanded Perlite (EP) greatly affected the properties of M30 concrete.
2) M1 mix (10% DE + 15% EP) showed best workability with a 90 mm slump and good flow.
3) M1 achieved highest compressive strength (36.50 N/mm²) and tensile strength (2.37 N/mm²).
4) M2 mix (15% DE + 15% EP) showed lower strength and workability due to excess water absorption by DE.
5) Tensile strength was 6.76–7.67% of compressive strength at 7 days and 6.49–6.93% at 28 days.
6) This indicates minor microcracks or weak bonding.
7) M1 mix with 10% DE, 15% EP, and Polytencrete NGT gave the best overall performance.

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