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A Study on Partial Replacement of Cement with Eggshell Powder (Esp) and Fine Aggregate with Robo Sand in M30 Concrete

G Prema Swathi[#1], Nathipam Kumar Siva Venkata Sunil[*2], Muliki Venkata Appa Rao[#3], Ayinavilli Laxman[#4], Md Zeeshan Khan[#5]

[#1] *Assistant Professor, Department Of Civil Engineering, Godavari Institute Of Engineering And Technology (Giet), Rajahmundry, Andhra Pradesh.*

[#2-5] *B.Tech, Student, Department Of Civil Engineering, Godavari Institute Of Engineering And Technology (Giet), Rajahmundry, Andhra Pradesh.*

Abstract

The construction industry is a major contributor to environmental degradation due to the excessive use of natural resources such as cement and river sand. Cement production generates significant carbon emissions, while uncontrolled extraction of river sand leads to ecological imbalance. This study focuses on developing sustainable concrete by partially replacing cement with eggshell powder (ESP) and fine aggregate with manufactured sand (robo sand). Eggshell powder, a bio-waste material rich in calcium carbonate ($CaCO_3$), was used as a cement replacement at levels of 0%, 3%, 6%, 8%, 10%, 12%, and 15%, while river sand was replaced with robo sand at proportions of 0%, 50%, and 100%.
Concrete specimens were prepared and tested for workability, compressive strength, and split tensile strength at curing periods of 7, 14, and 28 days. The workability of concrete was assessed using the slump test, which showed a gradual decrease in slump values with increasing ESP and robo sand content due to higher water demand and angular particle characteristics. However, all mixes remained within acceptable workability limits for structural applications.
The mechanical properties indicated that the inclusion of ESP improves the microstructure of concrete by acting as a filler material and enhancing particle packing. Robo sand further contributes to strength improvement due to better interlocking between particles. The optimum performance was observed at 10% ESP and 100% robo sand replacement, achieving a maximum compressive strength of 41 MPa at 28 days. Beyond this level, a reduction in strength was observed due to decreased cementitious content.
The study concludes that the combined use of ESP and robo sand can produce sustainable and high-performance concrete, reducing environmental impact and promoting eco-friendly construction practices..

Keywords

Eggshell Powder (ESP), Robo Sand, Sustainable Concrete, Compressive Strength, Flexural Strength, Split Tensile Strength, M30 Concrete

I. INTRODUCTION

The rapid growth of infrastructure development has led to increased demand for concrete, which is the most widely used construction material. Cement, a key ingredient of concrete, is responsible for significant carbon dioxide emissions during its production. It is estimated that cement manufacturing contributes approximately 7–8% of global CO_2 emissions. Additionally, the excessive use of river sand as fine aggregate has resulted in environmental issues such as riverbank erosion, depletion of groundwater, and loss of biodiversity.
To address these challenges, researchers have focused on incorporating waste materials and alternative resources in concrete production. Eggshell powder (ESP), a waste material generated from poultry and food industries, has gained attention due to its high calcium carbonate content. Since calcium carbonate is a primary component in cement manufacturing, ESP can be used as a partial replacement for cement. This not only reduces waste disposal issues but also decreases cement consumption, making concrete more sustainable.
Similarly, robo sand (manufactured sand) is emerging as a suitable alternative to river sand. It is produced by crushing hard stones into fine particles, ensuring uniform quality and controlled grading. Robo sand offers better interlocking due to its angular shape and is free from organic impurities, making it a reliable substitute for natural sand.

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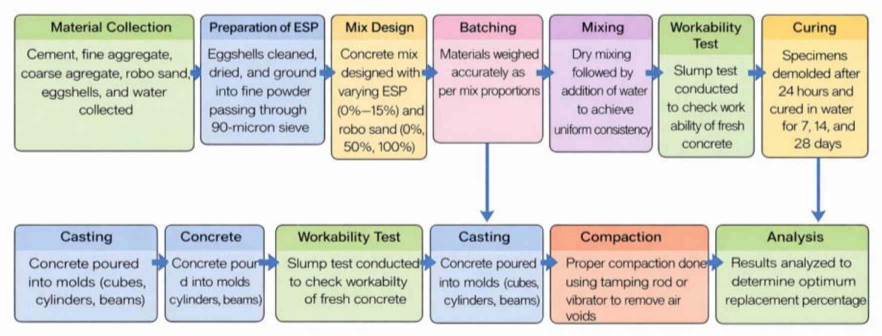
This study investigates the combined effect of ESP and robo sand on the mechanical properties of concrete. By replacing cement with ESP and fine aggregate with robo sand, the research aims to identify an optimum mix that enhances strength and durability while promoting sustainability.

II. METHODOLOGY

The methodology adopted in this study involves systematic steps starting from material collection to testing and analysis of concrete specimens.



III. MATERIALS USED

Cement (OPC 53 Grade)

Cement is the main binding material in concrete. In this study, Ordinary Portland Cement (OPC) 53 Grade is used because it provides high early strength and good durability. When water is added, cement undergoes a chemical reaction called hydration, which binds all materials together and forms a hard mass. It plays a major role in determining the strength and durability of concrete. Higher grade cement like OPC 53 is preferred for structural works such as beams, slabs, and columns due to its superior strength characteristics.

Eggshell Powder (ESP)

Eggshell powder is an agricultural waste material obtained from discarded eggshells. It mainly contains calcium carbonate ($CaCO_3$), which is similar to the composition of limestone used in cement. The eggshells are cleaned, dried, and ground into a fine powder passing through a 90-micron sieve. ESP acts as a filler material in concrete, improving particle packing and reducing voids. It also contributes slightly to strength due to its calcium content. Using ESP helps in reducing cement consumption and promotes sustainable construction.

River Sand

River sand is a natural fine aggregate obtained from river beds. It is widely used in concrete because of its smooth texture and good workability. It fills the spaces between coarse aggregates and helps in producing a dense concrete mix. However, excessive use of river sand leads to environmental issues such as riverbed depletion and ecological imbalance. In this study, river sand is partially or fully replaced with robo sand to reduce environmental impact.

Robo Sand

Robo sand, also known as manufactured sand (M-sand), is produced by crushing hard rocks in a controlled process. Unlike river sand, robo sand has angular and rough particles, which improve interlocking between particles. This results in better strength and bonding in concrete. It also reduces dependency on natural sand and helps in sustainable construction. In this study, robo sand is used as a partial and full replacement for river sand (50% and 100%)Coarse Aggregate

Coarse aggregate

Coarse aggregate consists of crushed stones of size up to 20 mm. It provides strength and stability to concrete. Coarse aggregates occupy the largest volume in concrete and help in resisting compressive loads. Their angular shape improves mechanical bonding with cement paste. Good quality coarse aggregate ensures durability and strength of concrete.

Water

Water is an essential component in concrete as it initiates the hydration process of cement. It helps in mixing all materials and provides workability to the concrete. The quality of water is very important; clean and potable water is generally used to avoid harmful chemical reactions. Proper water content ensures adequate strength, while excess water may reduce strength and durability.

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IV. Mix Proportions

A. Replacement Levels

In this study, concrete mix proportions were prepared by varying the percentage of cement replaced with Eggshell Powder (ESP) and fine aggregate replaced with robo sand. The following replacement levels were adopted:

Cement replaced by ESP:

0%, 3%, 6%, 8%, 10%, 12%, 15%

Fine aggregate replaced by robo sand:

0%, 50%, 100%

B. Explanation of Mix Proportions

1. Cement Replacement with ESP

Eggshell powder was used as a partial replacement for cement by weight. The selected percentages (0%–15%) were chosen to study the effect of gradual reduction in cement content on concrete properties.

- ✧ **0% ESP:** Control mix (no replacement)
- ✧ **3%–8% ESP:** Low replacement levels to study filler effect
- ✧ **10% ESP**: Expected optimum level based on performance
- ✧ **12%–15% ESP:** Higher replacement levels to observe strength reduction

ESP acts mainly as a filler material, improving particle packing and reducing voids. However, since it has limited cementitious properties, higher percentages may reduce strength due to decreased cement content.

2. Fine Aggregate Replacement with Robo Sand

Natural river sand was replaced with robo sand at different proportions to evaluate its effect on strength and durability.

- ✧ **0% Robo Sand:** Only river sand (conventional mix)
- ✧ **50% Robo Sand:** Equal mix of river sand and robo sand
- ✧ **100% Robo Sand:** Full replacement of river sand

Robo sand has angular particles and rough texture, which improve interlocking between particles. This leads to better bonding and higher strength compared to natural sand.

C. Combined Mix Combinations

The study involved combinations of ESP and robo sand to analyze their combined effect on concrete properties.

Total mixes = 7 (ESP levels) × 3 (robo sand levels) = 21 mixes

Each mix was prepared and tested for:

- ✧ Workability
- ✧ Compressive strength
- ✧ Split tensile strength
- ✧ Flexural strength
- ✧ Shear strength

D. Key Observations from Mix Proportions

Increasing ESP → reduces cement content

Increasing robo sand → improves particle interlocking

Combined effect → improves strength up to optimum level

V. Tests Performed

1.Collection and preparation of materials

2.Preparation of ESP (cleaning, drying, grinding)

3.Mix design (M30 grade)

4.Casting of cubes, cylinders, beams

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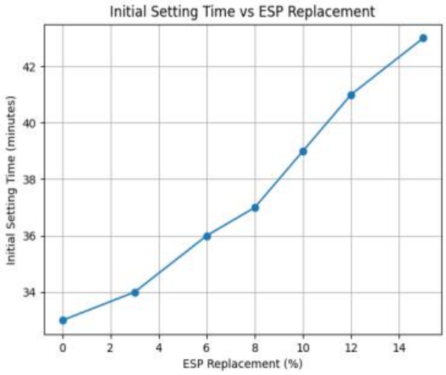
5.Curing (7, 14, 28 days)
6.Testing of specimens

VI. Tests and Discussions

Initial Setting Time of Cement with ESP

ESP %	Initial Setting Time (minutes)
0%	33
3%	34
6%	36
8%	37
10%	39
12%	41
15%	43



The graph shows a steady increase in initial setting time as the percentage of eggshell powder (ESP) increases. The trend is almost linear, indicating that ESP consistently delays the hydration process. Lower percentages (0–6%) show minimal variation, while higher percentages (10–15%) show a significant increase in setting time.

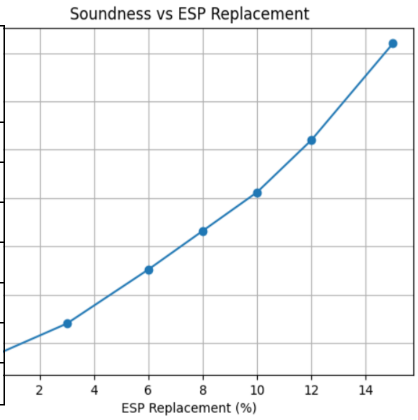
- Initial setting time increases with ESP content
- 3%–8% → Minimal impact
- 10% → Optimum range
- 12%–15% → Significant delay

Soundness Test of Cement with ESP (Calculations & Results)

Soundness of Cement with 0% ESP (Control Mix)

Final Summary Table

ESP %	Average Expansion (mm)
0%	5.33
3%	5.7
6%	6.26
8%	6.66
10%	7.06
12%	7.6
15%	8.6

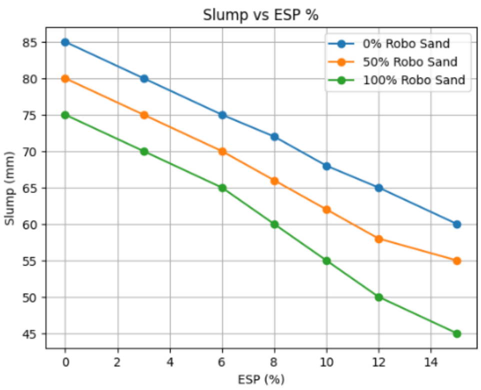


Final Observation

- Expansion **increases with ESP %**
- **0%–8% → Ideal range (5–7 mm)**
- **10% → Upper safe limit**
- **>12% → Not recommended**

Workability

ESP %	0% Robo Sand (mm)	50% Robo Sand (mm)	100% Robo Sand (mm)
0%	85	80	75
3%	80	75	70
6%	75	70	65



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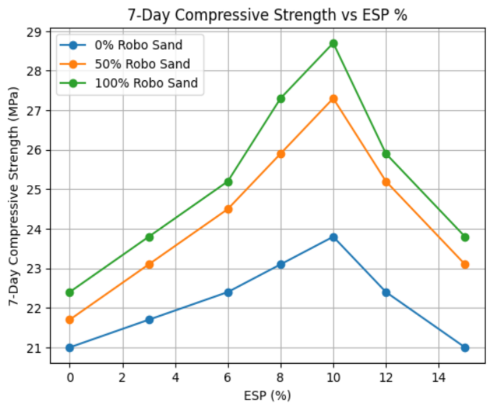
8%	72	66	60
10%	68	62	55
12%	65	58	50
15%	60	55	45

The slump values decreased with increasing esp and robo sand content due to higher surface area and angularity, however, all mixes remained within acceptable workability limits for structural concrete.

COMPRESSION RESULTS

Compressive Strength at 7 Days

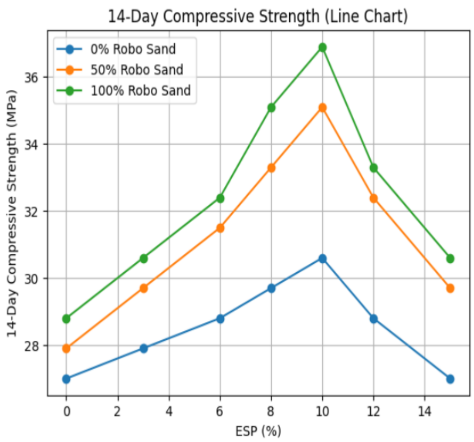
ESP %	0% Robo Sand (MPa)	50% Robo Sand (MPa)	100% Robo Sand (MPa)
0%	21	21.7	22.4
3%	21.7	23.1	23.8
6%	22.4	24.5	25.2
8%	23.1	25.9	27.3
10%	23.8	27.3	28.7
12%	22.4	25.2	25.9
15%	21	23.1	23.8



Early strength increases with ESP up to 10% due to filler effect. Robo sand improves early strength due to better particle interlocking and reduced voids.

Compressive Strength at 14 Days

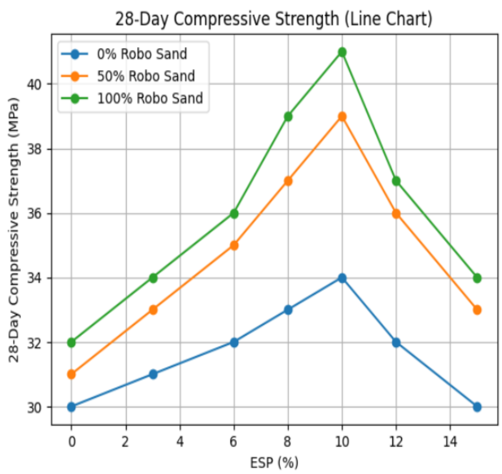
ESP %	0% Robo Sand (MPa)	50% Robo Sand (MPa)	100% Robo Sand (MPa)
0%	27	27.9	28.8
3%	27.9	29.7	30.6
6%	28.8	31.5	32.4
8%	29.7	33.3	35.1
10%	30.6	35.1	36.9
12%	28.8	32.4	33.3
15%	27	29.7	30.6



At 14 days, hydration improves strength significantly. Robo sand mixes show higher strength due to dense packing, while ESP improves bonding up to optimum level.

Compressive Strength after 28 Days Curing:

ESP %	0% Robo Sand (MPa)	50% Robo Sand (MPa)	100% Robo Sand (MPa)
0%	30	31	32
3%	31	33	34
6%	32	35	36
8%	33	37	39
10%	34	39	41
12%	32	36	37
15%	30	33	34



Maximum strength is achieved at **10% ESP** due to optimum filler and binding effect. 100% robo sand provides highest strength due to angular shape and better interlocking. Beyond 10% ESP, strength decreases due to reduced cement content.

Final Output from Results

The experimental results confirm that the incorporation of eggshell powder improves mechanical properties up to an optimum level of 10%. The use of robo sand significantly enhances compression strength due to its angular shape and improved interlocking characteristics. The combination of 10% ESP and 100% robo sand provides superior performance in all strength parameters, making it a sustainable and efficient alternative to conventional concrete.

VII. CONCLUSIONS AND DISCUSSIONS

A. Qualitative Analysis

The present study investigates the effect of partially replacing cement with Eggshell Powder (ESP) and fine aggregate with robo sand on the performance of M30 grade concrete, focusing on compressive strength and workability. The experimental results clearly indicate that both ESP and robo sand significantly influence the behavior of concrete.

The incorporation of ESP improves the microstructure of concrete due to its fine particle size and high calcium carbonate content. At lower replacement levels (3%–8%), ESP acts as a filler material, enhancing particle packing and reducing voids, which results in improved bonding between cement paste and aggregates. However, beyond the optimum level, ESP behaves as an inert material, reducing the effective cementitious content and thereby decreasing strength.

The use of robo sand as a replacement for natural sand has shown a noticeable improvement in compressive strength. This is mainly due to its angular shape and rough texture, which enhance inter-particle interlocking and reduce voids. Compared to conventional river sand, robo sand improves the density of concrete and contributes to higher strength.

Workability results indicate that the slump value decreases with increasing ESP and robo sand content. This reduction is attributed to the finer particles of ESP, which increase water demand, and the angular nature of robo sand, which reduces flowability. However, all mixes maintained acceptable workability within the medium range, making them suitable for structural applications.

The combined use of ESP and robo sand demonstrates a balanced performance, where ESP improves the internal microstructure and robo sand enhances mechanical interlocking.

B. Quantitative Analysis

The quantitative results clearly demonstrate the effect of ESP and robo sand on compressive strength and workability. The compressive strength of conventional concrete (0% ESP, 0% robo sand) at 28 days was observed to be 30 MPa, which increased to a maximum of 41 MPa at 10% ESP with 100% robo sand, representing an improvement of approximately 36.7%.

The results also indicate that replacing natural sand with 50% and 100% robo sand increases compressive strength by approximately 15–25% and 25–35%, respectively. However, increasing ESP beyond 10% leads to a reduction in strength due to a decrease in cementitious material.

In terms of workability, slump values decreased from 85 mm (control mix) to 45 mm (15% ESP + 100% robo sand). Despite this reduction, all mixes remained within the acceptable range of 50–100 mm, indicating adequate workability for practical applications.

Strength development followed the expected trend, with 7-day strength reaching approximately 70% and 14-day strength reaching about 90% of the 28-day strength, confirming proper hydration and strength gain.

Outcomes

Based on both qualitative and quantitative analysis, it can be concluded that:

- ✧ Optimum Mix: 10% ESP + 100% Robo Sand
- ✧ Provides maximum compressive strength
- ✧ Maintains acceptable workability
- ✧ Enhances sustainability by reducing cement and natural sand usage.

II. Advantages

- Reduces cement consumption
- Utilizes waste material (ESP)
- Reduces environmental impact
- Improves strength and durability
- Reduces dependency on river sand

III. Limitations

- Excess ESP reduces strength
- Workability decreases at higher ESP
- Requires proper mix design

IV. Conclusion

The study concludes that eggshell powder and robo sand can be effectively used to produce sustainable concrete. The optimum replacement level is found to be 10% ESP with 100% robo sand, which provides maximum strength and durability. The use of these materials not only enhances concrete performance but also contributes to environmental sustainability by reducing waste and conserving natural resources.

V. Future Scope

- Use of ESP with other materials (fly ash, silica fume)
- Durability studies (acid, sulfate resistance)
- Field applications
- Cost analysis

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