Experimental Investigation on Properties of Concrete by Partial Replacement of Cement with Groundnut Shell Ash and Metakaolin

PITTI VENKATASUNEEL[1], POLA NAGA LAKSHMI[2]

[1]*Assistant professor, Department of Civil Engineering & Srinivasa Ramanujan Institute of Technology (Autonomous), Ananthapuramu, A.P*

[2] *Assistant professor, Department of Civil Engineering & Srinivasa Ramanujan Institute of Technology (Autonomous), Ananthapuramu, A.P*

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Abstract - Concrete is a widely utilized material in the construction industry, forming the foundation of numerous buildings, bridges, and infrastructure projects across the globe. Given its extensive use, concrete is often referred to as the backbone of construction. However, India faces challenges in meeting the demand for cement, a critical component of concrete, as domestic production falls short of requirements. This imbalance between supply and demand contributes to increased construction costs. To address these issues, numerous studies have explored the partial replacement of cement and sand with alternative materials. In this project, cement is partially replaced with groundnut shell ash (GSA) at 20% and metakaolin (MK) at varying levels (0%, 5%, 10%, and 15%) using M20 grade concrete with a water-cement ratio of 0.6. Five trial mixes were prepared to evaluate mechanical properties such as compressive strength, split tensile strength, ductility, and wear resistance. For each mix, four concrete cubes and four cylinders were cast. The standard cube size of 150 mm x 150 mm x 150 mm was used to assess compressive strength, while standard cylinders with a diameter of 150 mm and a height of 300 mm were tested for split tensile strength. These specimens were cured and tested at intervals of 7 and 28 days, with the results compared to those of conventional concrete. The findings analyzed both mathematically and graphically, indicate that the compressive strength and split tensile strength of the modified concrete are lower than those of conventional concrete. This study highlights the potential and limitations of using GSA and MK as partial cement replacements in concrete.

Key Words: Groundnut Shell Ash (GSA) and Metakaolin (MK)

1.INTRODUCTION

In earlier times, mortar was predominantly used for construction purposes. Today, however, concrete has become the primary material in construction due to its superior strength. The main difference between mortar and concrete lies in their composition and strength; concrete is much stronger than mortar. Concrete is made by mixing cement, sand (fine aggregate), gravel or crushed stone (coarse aggregate), and water, whereas mortar uses only sand as its aggregate.

Concrete is one of the most extensively used materials in construction, with an annual consumption of approximately 7.3 million cubic meters in India alone. However, the production of cement, a key component of concrete, is a significant contributor to environmental issues, including global warming. To mitigate these impacts, researchers are investigating sustainable alternatives. These include the use of metakaolin, a pozzolanic material derived from kaolin, and recycling waste materials, such as eggshells, to minimize environmental damage.

2. LITERATURE REVIEW

A.V.S. Sai Kumar and Krishna Rao[1] explored partial cement replacement with Quarry Dust and Metakaolin. They found that 25% Quarry Dust replacement maintained acceptable standards, while 12.5% Metakaolin replacement yielded positive results. The study tested crushing load, split tensile strength, and flexural strength over 7, 28, and 90 days. J. Karthick, R.J. Enanthic, and M. Petchiyammal[2] replaced sand with Eggshell Powder (10-50%) in an M25 concrete mix. Compressive strength met requirements at 20% replacement, but tensile and flexural strengths decreased with higher eggshell content. Concrete cube weight decreased by 0.8-2.8%. S.A. Raji and A.T. Samuel[3] replaced 100% of fine aggregate with eggshells and tested 18 concrete cubes for strength development. The results, based on the use of 43-grade Ordinary Portland Cement and standard aggregate sizes, were compared to conventional concrete using sand. J. Thivya and M. Arivukkarasi[4] partially replaced cement with Metakaolin (5-20%) and fine aggregate with Granite Powder (10-25%). Strengths in compressive, split tensile, and flexural tests increased with time, showing compressive strength between 26.82 and 29.02 N/mm² over 7, 14, and 28 days. A. Kaur and V.P.S. Sran[5] investigated Metakaolin (0-12%) replacement in M30 concrete. The highest compressive and split tensile strengths were achieved at 12% Metakaolin addition, with strength evaluations conducted at 7, 14, and 28 days. M. Narmatha and Dr. T. Felixkala[6] studied partial cement replacement with Metakaolin in M60 grade concrete. They observed compressive strength between 64.6 and 73 MPa at 28 days, with split tensile and flexural strengths peaking at 10-15% Metakaolin replacement. Dr. B. Krishna Rao and M. Anil Kumar[7] replaced cement with 10% Metakaolin and fine aggregate with 10-40% waste foundry sand in M25 concrete. The study evaluated compressive, split tensile, and flexural strengths at 7, 28, and 56 days, comparing the properties of various mixes. Divya B., Vasanthavalli K., and Ambalavanam[8] partially replaced cement with Eggshell Powder (5-20%) due to its calcium content. A concrete mix of 1:1.5:3 was used, and compressive strength was tested at 7 and 28 days, showing potential as a sustainable alternative. Asgher Hasan and Bhawna[9] replaced cement with varying percentages of Eggshell Powder (ESP) and Metakaolin (MK). The mix with 10% ESP and MK achieved the highest compressive strength of 48.25 N/mm², with compressive and flexural strengths tested at 7 and 28 days. K. Pradeeba et.al[10] studied partial sand replacement with Eggshell and M-sand in M20 grade concrete. Compressive strength tests at 28 days showed values ranging from 18.3 to 14.25 N/mm², with eggshell replacement leading to reduced strength.

3. METHODOLOGY

After extensive research, cement and fine aggregate are partially replaced with metakaolin and eggshell granules in this study. The properties of these materials were tested in the laboratory following standard codes to ensure accurate results. Understanding these properties helps engineers design concrete mixes for specific strength requirements.

Cement: In this research, Ordinary Portland Cement (OPC), a widely used construction material composed of calcium, silica, alumina, and iron, was utilized. The 53 Grade OPC, known for its superior strength, was selected due to its quality and durability enhancements.

Table - 1. Properties of Cement

S.NO	Description of Test	Results
1	Fineness of Cement	7
2	Initial Setting Time	35 min
3	Normal Consistency	31%
4	Specific Gravity	3.15

Coarse aggregate: In this study, coarse aggregates, consisting of irregular stones or gravel retained on a 4.75mm IS sieve, were used. Aggregates measuring 20mm in size were selected and tested as per IS: 383-1970 standards. Crushed aggregates enhance concrete strength through better particle interlocking.

Table - 2. Properties of Coarse aggregate

S.NO	Properties	Results
1	Specific Gravity	2.844
2	Water absorption	1.8%
3	Crushing Value	19%

Fine aggregates: Fine aggregates play a crucial role in concrete mix design, with properties like fineness modulus, moisture content, specific gravity, and silt content affecting proportions. Moisture content influences water requirements, while specific gravity impacts the strength of the concrete. Excessive silt in fine aggregates can increase water demand and reduce strength.

Table - 3. Properties of Fine aggregate

S.NO	Properties	Results
1	Specific Gravity	2.64
2	Water absorption	2.0%

Groundnut shell ash: Concrete is a vital material in the construction industry. However, with its increasing demand and limited availability, there is a need to explore alternative materials for replacement. Various waste products, such as paper waste, red mud, rice husk, and plastic waste, have been studied as substitutes. Among these, groundnut shell ash, a by-product of the oil industry, shows great potential for replacing cement.

Fig -1: Groundnut shell ash

Table - 4. Chemical properties of Groundnut shell ash

Constituent	Percentage
Silica (SiO2)	16.3
Ferric Oxide Calcium Oxide (Fe2O3)	1.7
Calcium Oxide (CaO)	8.69
Alumina (Al2O3)	6
Magnesium Oxide (MgO)	7
Potassium Oxide (K2O)	16

Metakaolin: In this research, Metakaolin, a pozzolanic material obtained by calcining kaolinite clay at 650°-800°, was used. Its fine particles improve the compressive and flexural strength of concrete, enhancing its durability. Metakaolin also reduces permeability and increases resistance to chemical attacks, such as sulfate exposure

Fig -2: Metakaolin

Table - 5. Chemical properties of Metakaolin

Metakaolin Chemical Composition	Percentage
Silica (SiO2)	54.3
Alumina (Al2O3)	38.3
Calcium Oxide (CaO)	0.39
Ferric Oxide Calcium Oxide (Fe2O3)	4.28
Magnesium Oxide (MgO)	0.08

Potassium Oxide (K2O)	0.50
Sulphury anhydride	0.22

4. TESTS ON HARDENED CONCRETE

Compressive strength Test: Compressive strength is a key test that assesses a material's ability to endure loads without breaking or deforming. In concrete, the compressive strength test of a cube offers insights into cement quality. Factors such as water-cement ratio, bonding quality, and material quality affect the test. Concrete is cast in 15cm x 15cm x 15cm cubes, cured in water for 24 hours, and then tested at 7, 14, and 28 days using a compressive testing machine, following IS: 516-1957 standards. In India, compressive strength is classified into grades based on the 28-day strength of 150mm cubes (fck), with no more than 5% of results expected below this value. This value is adjusted for design purposes by applying a safety factor, depending on the design philosophy.

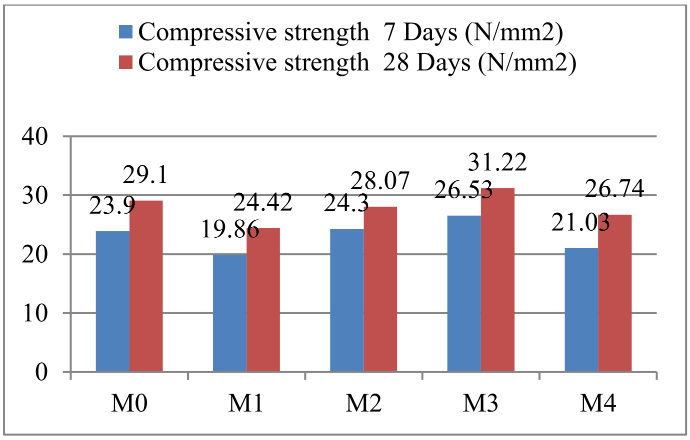
Table - 6. Compressive strength for 7 days

Mix No.	Mix Proportions	Average compression strength (N/mm^2)
M0	NOMINAL MIX	23.9
M1	C (80%) +GNSA (20%) +MK (0%)	19.86
M2	C (75%) +GNSA (20%) +MK (5%)	24.3
M3	C (70%) +GNSA (20%) +MK (10%)	26.53
M4	C (65%) +GNSA (20%) +MK (15%)	21.03

Table - 7. Compressive strength for 28 days

Mix No.	MIX PROPORTIONS	Average compression strength (N/mm^2)
M0	NOMINAL MIX	29.1
M1	C (80%) +GNSA (20%) +MK (0%)	24.42
M2	C (75%) +GNSA (20%) +MK (5%)	28.07
M3	C (70%) +GNSA (20%) +MK (10%)	31.22
M4	C (65%) +GNSA (20%) +MK (15%)	26.74

Graph 1. Compressive strength for 7 and 28 days



The study shows that replacing cement with Groundnut Shell Ash (GNSA) and Metakaolin (MK) in concrete mixes influences compressive strength positively, with the best results observed at 10% MK replacement. The compressive strength increases over time, with significant growth from 7 and 28 days for all mixes. Among the various mixes, the combination of 70% cement, 20% GNSA, and 10% MK (M3) demonstrated the highest compressive strength at both 7 and 28 days. Overall, incorporating these materials can enhance concrete's strength and durability while reducing environmental impact.

Split Tensile Strength: The Split Tensile Strength Test measures the ability of concrete to resist tension by applying a load along the diameter of a cylindrical specimen. The test is conducted on cylindrical samples, typically 150mm in diameter and 300mm in height, following IS: 5816 standards. A compressive load is applied until the cylinder splits, and the tensile strength is calculated based on the maximum load at failure. This test helps assess the concrete's durability and its ability to withstand cracking under tensile forces. Results were graphically represented in table:

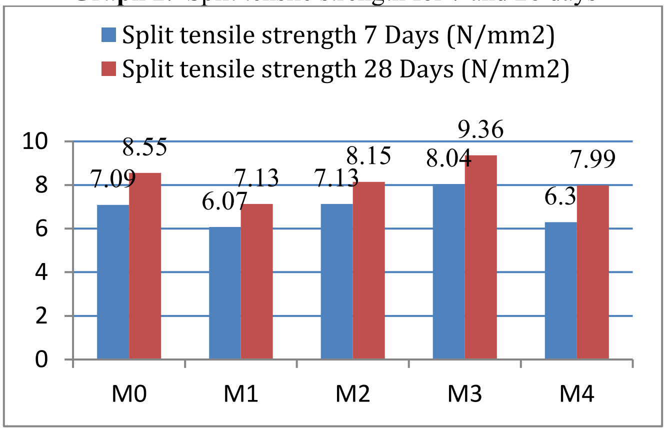
Table - 8. Split Tensile Strength for 7 days

Mix No.	Mix Proportions	Split tensile strength (N/mm^2)
M0	NOMINAL MIX	7.09
M1	C (80%) +GNSA (20%) +MK (0%)	6.07
M2	C (75%) +GNSA (20%) +MK (5%)	7.13
M3	C (70%) +GNSA (20%) +MK (10%)	8.04
M4	C (65%) +GNSA (20%) +MK (15%)	6.3

Table - 9. Split Tensile Strength for 28 days

Mix No.	Mix Proportions	Split tensile strength (N/mm^2)
M0	NOMINAL MIX	8.55
M1	C (80%) +GNSA (20%) +MK (0%)	7.13
M2	C (75%) +GNSA (20%) +MK (5%)	8.15
M3	C (70%) +GNSA (20%) +MK (10%)	9.36
M4	C (65%) +GNSA (20%) +MK (15%)	7.99

Graph 2. Split tensile strength for 7 and 28 days



The study demonstrates that the addition of Groundnut Shell Ash (GNSA) and Metakaolin (MK) as partial replacements for cement positively impacts the split tensile strength of concrete. The split tensile strength increases over time for all mixes, with the highest value observed in the mix containing 70% cement, 20% GNSA, and 10% MK (M3), showing significant improvement from 7 to 28 days. While the nominal mix (M0) showed a steady increase, the modified mixes, particularly M3, outperformed the others, highlighting the effectiveness of using GNSA and MK to enhance concrete's tensile strength. The results indicate that this approach can contribute to stronger, more durable concrete with improved resistance to cracking.

5. CONCLUSION

Based on the findings of this investigation, it can be concluded that the use of Groundnut Shell Ash (GNSA) and Metakaolin as partial replacements for cement not only enhances concrete strength but also offers an environmentally friendly and cost-effective solution. The combination of 20% GNSA and 10% Metakaolin yielded the highest compressive and tensile strength at both 7 and 28 days, proving to be the optimal mix. This substitution reduces the environmental impact by effectively utilizing waste materials, lowers construction costs, and contributes to the safe disposal of groundnut shells. The results suggest that this combination can be effectively implemented in concrete for structural applications.

The future scope of this research involves optimizing mix ratios of Groundnut Shell Ash (GNSA) and Metakaolin to enhance concrete properties such as durability and resistance to chemical attacks. Further studies on the long-term performance of concrete incorporating these materials and their behavior under various environmental conditions are essential. Exploring other industrial waste materials and evaluating the economic and environmental benefits of large-scale application can promote sustainable, cost-effective construction practices.

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BIOGRAPHIES

Mr.P.Venkata Suneel
Assistant Professor
Department of Civil Engineering
Srinivasa Ramanujan Institute of Technology (Autonomous)

Mrs.P.Naga Lakshmi
Assistant Professor
Department of Civil Engineering
Srinivasa Ramanujan Institute of Technology (Autonomous)