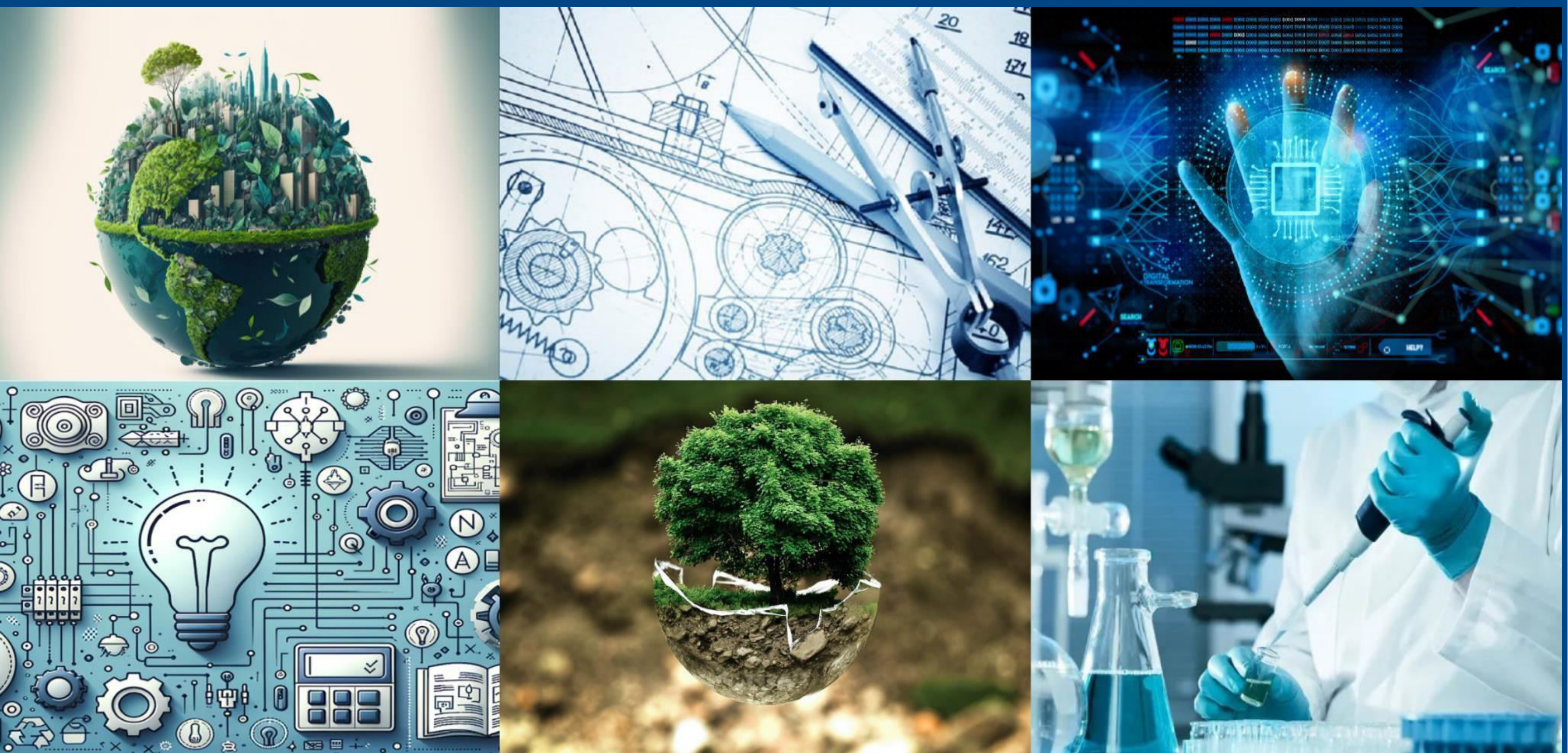
ISSN: 2582-7219

International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 8, Issue 11, November 2025

www.ijmrset.com ijmrset@gmail.com +91 6381 907 438 +91 63819 07438

© 2025 IJMRSET | Volume 8, Issue 11, November 2025| DOI:10.15680/IJMRSET.2025.0811047

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Performance of Concrete Containing Palm Oil Fuel Ash and Metakaolin as Cement Replacement Material

Munnangi Vineela[1,*], Krishna Rao Boddepalli[2]

PG Scholar, Department of Civil Engineering, University College of Engineering Kakinada, JNTUK, AP, India[1]

Professor, Department of Civil Engineering, University College of Engineering Kakinada, JNTUK, AP, India[2]

Corresponding author Email: vineelamunnagi3@gmail.com

ABSTRACT: This study investigates the mechanical performance of M30 grade concrete incorporating Metakaolin and Palm Oil Fuel Ash (POFA) as partial replacements for cement to enhance sustainability and reduce CO_2 emissions. Metakaolin 10% was kept constant, while POFA was varied at 0%, 5%, 10%, 15%, and 20%. Fresh and hardened properties were evaluated, including compressive strength, split tensile strength, and flexural strength at 7 and 28 days. The 28-day compressive, split tensile, and flexural strengths achieved were 43.56 N/mm², 3.62 N/mm², and 5.647 N/mm² respectively. Among all mixes, the combination with 10% POFA showed the highest strength, establishing it as the optimum replacement level. The results confirm that the use of Metakaolin and POFA improves concrete performance while promoting sustainable construction.

KEYWORDS: Metakaolin, palm oil fuel ash, cement replacement, pozzolanic concrete, durability, sustainable construction.

I. INTRODUCTION

Concrete is the most widely used construction material due to its high compressive strength, durability, and versatility. However, the production of Ordinary Portland Cement (OPC), the primary binding component in concrete, generates significant CO_2 emissions and consumes large amounts of natural resources, making it a major contributor to environmental degradation. To address these challenges, the use of Supplementary Cementitious Materials (SCMs) has gained attention as a sustainable strategy to partially replace cement without compromising performance. Palm Oil Fuel Ash (POFA), an agricultural by-product obtained from burning palm oil residues, exhibits pozzolanic properties when finely processed and can enhance long-term strength, reduce permeability, and provide an eco-friendly waste-utilization solution. Metakaolin, produced by calcining kaolin clay, is a highly reactive SCM known for improving early strength, refining microstructure, and enhancing durability. Combining POFA and Metakaolin in concrete offers the potential for improved mechanical and durability characteristics due to their complementary effects. This study investigates the performance of M30 grade concrete incorporating varying percentages of POFA with a constant 10% Metakaolin replacement. The objective is to determine the optimum replacement level and assess the impact of these materials on workability and mechanical properties, contributing to the development of more sustainable concrete mixtures.

1.1 Need of the study

Increasing cement consumption in concrete production contributes heavily to CO_2 emissions and resource depletion, creating the need for sustainable alternatives. Supplementary cementitious materials like Palm Oil Fuel Ash (POFA) and Metakaolin offer environmental benefits and improve concrete performance through their pozzolanic properties. However, their combined use has not been widely studied. This research is needed to evaluate whether incorporating both POFA and Metakaolin can effectively reduce cement usage while enhancing the strength and durability of concrete.

© 2025 IJMRSET | Volume 8, Issue 11, November 2025| DOI:10.15680/IJMRSET.2025.0811047

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

1.2 Objective of testing

- By testing fresh concrete for workability and hardened concrete for compressive strength, split tensile strength, flexural strength, we can verify its performance under different conditions and confirm that the concrete will be strong and durable for structural use.
- In this study, cement is partially replaced with both Metakaolin and POFA to determine the optimum percentage of replacement that gives maximum strength.
- To study the workability and strength properties of concrete of grade M30.
- Developing mix design for concrete relevant to IS:10262-2009.
- To study the effect of concrete, when cement with partial replacement of both metakaolin and palm oil fuel ash.

II. MATERIAL PROPERTIES

The following are the materials are used in this study

- Cement: OPC cement of 53 Grade is used.
- Fine Aggregate: Locally available river Godavari sand conforming to IS (Zone-II).
- Coarse Aggregate: Locally available quarry stone which s passing through 20mm and retained on 10mm sieve.
- Metakaolin obtained from Viruksha Enterprises.
- POFA obtained from Palm Oil Industry.
- Water: Ordinary portable water which is available in the laboratory.
- Super Plasticizer: CONPLAST SP 430 is compatible with their types of FORSOC admixtures.

2.1 Cement

Ordinary Portland Cement (OPC) is widely used in construction for its high strength, quick setting, and versatility. Made by grinding clinker with gypsum, it comes in three grades 33, 43, and 53 based on 28-day compressive strength. Grade 53 is used for high-strength concrete, while Grade 33 suits masonry and plastering. OPC is durable and works well with admixtures, making it ideal for structures like bridges, pavements, and precast elements. However, its production is energy-intensive and emits significant CO_2, encouraging the use of more sustainable alternatives.

2.2 Aggregates

Aggregates are granular materials used in construction, primarily in concrete and road building. They include coarse aggregates (like gravel and crushed stone) and fine aggregates (like sand). Aggregates provide bulk, strength, and stability to concrete, and their quality effects durability, workability, and strength. Ideal aggregates should be clean, hard, and well-graded to ensure proper bonding with cement.

Coarse aggregates are granular materials used in concrete that have a particle size greater than 4.75 mm, typically ranging up to 80 mm. They are usually obtained from natural sources like river gravel or crushed rocks, or manufactured from crushed stone or slag. Fine aggregates consist of small granular materials with particle sizes between 0.075 mm and 4.75 mm, mainly obtained from natural sand or crushed stone sand.

Table 1 Properties of Fine and Coarse Aggregates

S. No	Property		C.A	F.A
1	Specific gravity		2.51	2.54
2	Bulk density	Loose	1500.74kg/m^3	1562.96 kg/m^3
		Compacted	1659.25kg/m^3	1681.48 kg/m^3
3	Sieve analysis		2.79	5.51

2.3 Metakaolin

Metakaolin is a highly reactive pozzolanic material produced by heating purified kaolin clay at 700–800°C, which converts it into an amorphous form. When used as a partial replacement for cement, it reacts with calcium hydroxide to form additional C–S–H gel, resulting in higher strength, reduced porosity, and improved durability of concrete. It enhances resistance to chemical attacks, lowers permeability, and reduces the heat of hydration, making it useful for

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

durable and sustainable concrete. Metakaolin also helps reduce CO_2 emissions by decreasing cement usage while improving both mechanical and durability properties.

Figure 1 Metakaolin

2.4 Palm oil fuel ash

Palm Oil Fuel Ash (POFA) is a silica-rich byproduct from burning palm oil waste, and it acts as a pozzolanic material in concrete. When used as a partial cement replacement, it reacts with calcium hydroxide to form extra C–S–H gel, improving strength, reducing permeability, and increasing resistance to sulfate and chloride attacks. Although early strength may be lower, POFA enhances long-term durability and supports sustainable construction by reducing cement usage and utilizing industrial waste.

Figure 3 Palm Oil Fuel Ash

2.5 Plasticizer

CONPLAST SP 430 is used in this study to achieve a high degree of workability and good slump retention, especially in situations where delays in transportation or high ambient temperatures may cause rapid slump loss. It helps in producing high-quality, dense, and durable concrete. The admixture complies with IS 9103:1999, BS 5075 Part 3, and ASTM C-494 Type F (high-range water reducer) and Type G at higher dosages. CONPLAST SP 430 provides up to 25% water reduction without compromising workability, resulting in concrete with improved strength and reduced permeability.

Figure 4 Superplasticizer used in this study

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

III. METHODOLOGY

3.1 Optimization of metakaolin

Metakaolin is used as a partial cement replacement to evaluate its impact on the strength, durability, and workability of concrete at levels of 5%, 10%, 15%, and 20%. The goal is to identify the most effective percentage that enhances concrete performance without affecting fresh properties. Studies indicate that a 10–15% replacement provides the greatest improvement, increasing compressive strength, reducing permeability, and refining the microstructure through its strong pozzolanic reaction. Beyond 15%, workability and strength may decrease due to the higher fines content and lower available cementitious material.

The concrete mixes were prepared using 10% and 15% metakaolin as partial replacements for cement. The mix with 10% metakaolin gives the compressive strength of 25.86N/mm^2 and mix containing 15% metakaolin gives the 23.68N/mm^2. Among the two proportions, the mix containing 10% metakaolin showed higher compressive strength compared to the 15% replacement. This indicates that 10% metakaolin is more effective in enhancing the strength properties of concrete than the higher replacement level.

3.2 Mix proportions

The study focuses on evaluating the mechanical properties of M30 grade concrete. The mix design was developed using IS 10262 and SP 23 guidelines, giving a proportion of 1:1.51:2.65 with a water–cement ratio of 0.43. POFA was incorporated as a partial cement replacement at levels of 0%, 5%, 10%, 15%, and 20%, while Metakaolin was maintained at a constant 10% throughout the investigation. The Mix ratio of the experiments maintained in the mixes is 1: 1.51:2.65:0.43(Table 2)

3.3 Mixing, Casting and Curing

The materials were mixed in a pan mixer, beginning with coarse and fine aggregates for 2 minutes, followed by the addition of cementitious materials and mixing for another minute. Water was added in three stages, with the superplasticizer blended into the final portion to ensure even distribution. The mix was then blended for about 5 minutes to achieve a uniform consistency, and a slump test was carried out to assess workability. Concrete specimens—cubes (150×150×150 mm), cylinders (300×150 mm), and beams (150×150×700 mm)—were cast for strength testing at 7 and 28 days. After casting, the specimens were kept at room temperature for 24 hours and then transferred to water for curing.

Table 2 Mix proportions of this experimental program.

Mix ID	Metakaolin (%)	POFA (%)	Cement (kg/m^3)	Metakaolin (kg/m^3)	POFA (kg/m^3)	CA (kg/m^3)	Water (kg/m^3)	SP (%)
M1	0	0	412.32	0	0	1096	177	0.18
M2	10	5	371	41	20	1096	177	0.18
M3		10	371	41	41	1096	177	0.18
M4		15	371	41	61	1096	177	0.18
M5		20	371	41	82	1096	177	0.18

3.4 Workability

The slump test is the simplest workability test for concrete, involves low cost and provides immediate results. The slump is carried out as per procedures mentioned in IS: 1199-1959 in India. Generally concrete slump value is used to find the workability, which indicates water-cement ratio, but there are various factors including properties of materials, mixing methods, dosage, admixtures etc., also effect the concrete slump value

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

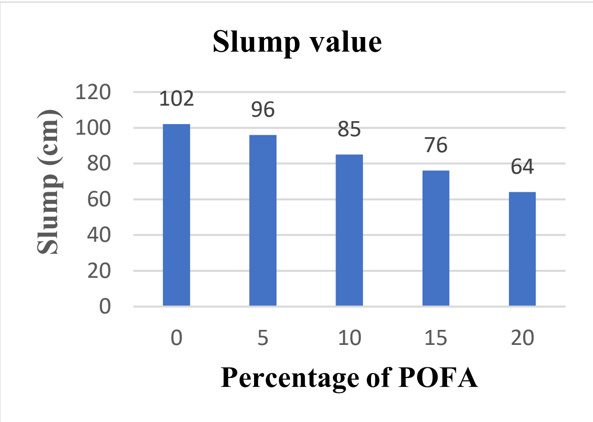
International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

IV. RESULTS AND DISCUSSIONS

4.1 Slump test

The slump results indicate a steady decline in workability with increasing metakaolin content. The control mix showed the highest slump of 102 mm, which decreased to 96 mm at 5% and 85 mm at 10% metakaolin. At higher replacement levels, the slump dropped more noticeably to 76 mm at 15% and 64 mm at 20%. This reduction is mainly due to the fine particle size and high surface area of metakaolin, which increases water demand and lowers the overall flowability of the concrete mix.



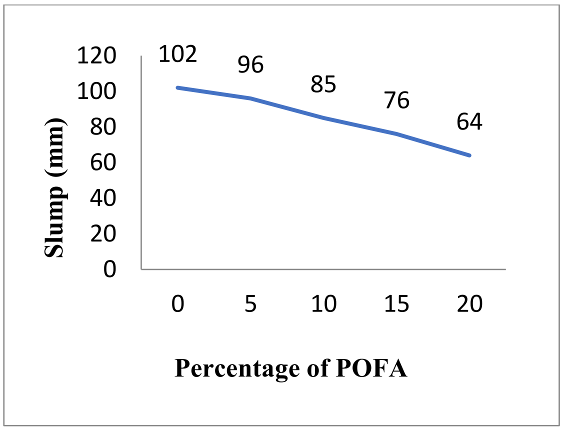


Figure 2 Slump test results of POFA.

4.2 Compressive strength

The compressive strength results for concrete with different POFA percentages at 7 and 28 days show that strength varies with the replacement level. The control mix reached 34.83 N/mm² at 7 days and 38.41 N/mm² at 28 days. At 5% POFA, the 7-day strength dropped to 30.46 N/mm², while the 28-day strength rose to 35.22 N/mm². The 10% POFA mix showed the highest strength, achieving 38.46 N/mm² at 7 days and 43.56 N/mm² at 28 days, indicating it as the optimum replacement level. At 15% POFA, the strengths were 35.26 N/mm² and 40.15 N/mm², and at 20% they further reduced to 30.58 N/mm² and 34.52 N/mm². These results indicate that 10% POFA provides the maximum compressive strength, while higher replacement levels decrease strength due to excess fines and reduced effective cementitious content

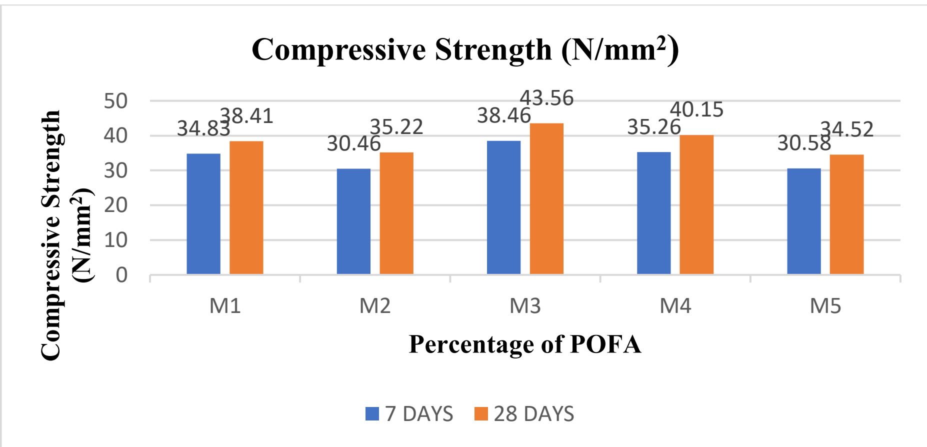


Figure 3 Compressive strength results of experimental mixes.

4.3 Split tensile strength

The split tensile strength of concrete with varying POFA percentages was measured at 7 and 28 days, showing that strength depends on the replacement level. The control mix reached 2.22 N/mm² at 7 days and 3.35 N/mm² at 28 days. At 5% POFA, the strengths slightly decreased to 2.13 N/mm² and 3.10 N/mm². The 10% POFA mix showed the highest values, recording 2.49 N/mm² at 7 days and 3.62 N/mm² at 28 days. Strengths for 15% replacement were 2.20 N/mm² and 3.20 N/mm², while the 20% POFA mix dropped to 2.00 N/mm² and 2.90 N/mm². These results confirm that 10% POFA provides the optimum split tensile strength, while higher percentages reduce strength due to excess fines and lower effective cementitious content.

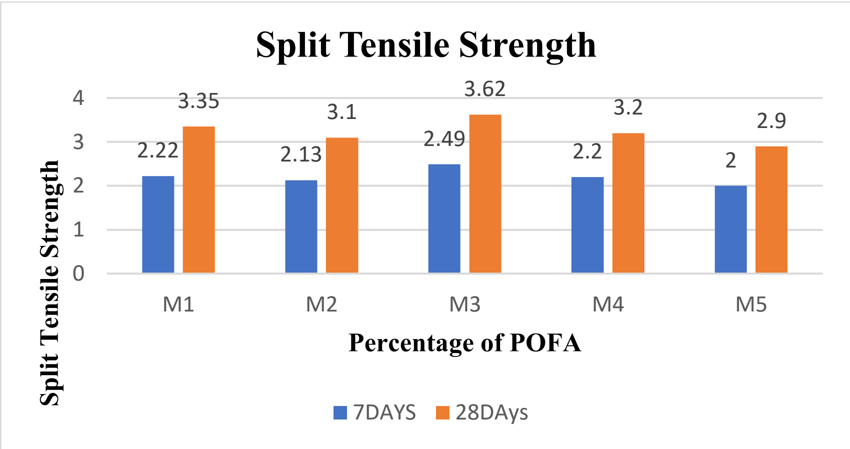


Figure 4 Split tensile strength results of experimental mixes.

4.4 Flexural strength

The flexural strength results of concrete with varying POFA percentages show a trend of improvement up to an optimum level, followed by a gradual reduction at higher replacement levels. The control mix M1 (0% POFA) achieved strengths of 4.14 N/mm² at 7 days and 5.41 N/mm² at 28 days. With 5% POFA (M2), the flexural strength increased to 4.72 N/mm² and 5.52 N/mm², respectively. The maximum enhancement was observed at 10% POFA (M3), where strengths reached 4.83 N/mm² at 7 days and 5.67 N/mm² at 28 days, indicating this as the optimum replacement percentage. However, increasing POFA to 15% (M4) slightly reduced the values to 4.77 N/mm² and 5.23 N/mm², while a further rise to 20% POFA (M5) resulted in lower strengths of 4.52 N/mm² and 5.10 N/mm². Overall, the results show that moderate POFA replacement improves flexural strength due to its pozzolanic activity and microstructure refinement, whereas higher POFA content introduces excess fines, increases water demand, and reduces bonding efficiency, leading to decreased flexural performance.

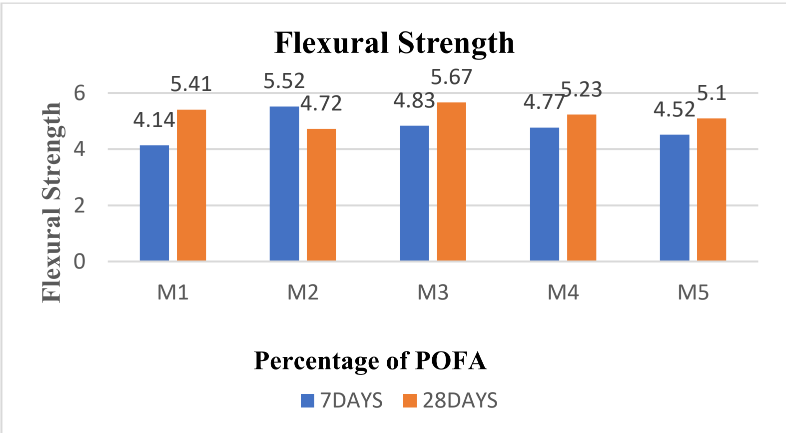


Figure 5 Flexural strength results of experimental mixes.

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

V. CONCLUSIONS

The study examined the strength properties of concrete with partial replacement of cement by Metakaolin and POFA. Metakaolin was kept constant at 10%, while POFA was varied at 5%, 10%, 15%, and 20%.

- The results show that 10% POFA provides higher strength compared to the conventional mix and the other replacement levels, indicating it as the optimum dosage.
- The compressive strength improved significantly at 10% POFA, giving 38.46 N/mm² at 7 days and 43.56 N/mm² at 28 days, outperforming both the control mix and other POFA percentages.
- Beyond 10% POFA, the compressive strength decreased gradually due to excess fines and reduced effective cementitious content.
- The split tensile strength at 10% POFA reached 2.49 N/mm² at 7 days and 3.62 N/mm² at 28 days, showing the best performance among all mixes.
- The flexural strength also peaked at 10% POFA, recording 4.83 N/mm² at 7 days and 5.67 N/mm² at 28 days.
- All strength parameters compressive, split tensile, and flexural show a consistent increase at 10% POFA compared to conventional concrete.
- Therefore, combining 10% Metakaolin with 10% POFA is identified as the optimum replacement level to achieve improved mechanical properties and overall better concrete performance.

5.1 SCOPE FOR FUTURE PROJECT

- To study the durability of concrete with this partial replacement of materials.
- To study the strength characteristics of high strength concrete with this partial replacement of materials.
- To study young modulus of concrete with this partial replacement of materials.

REFERENCES

1. Oyejobi, D. O., Abdulkadir, T. S. and Ahmed, A. T., A Study of “Partial Replacement of Cement with Palm Oil Fuel Ash in Concrete Production”, 2015.
2. Aiswarya V S, Beyoola Wilson, Harsha V N, studied on “Palm Oil Fuel Ash as Partial Replacement of Cement in Concrete”, 2017.
3. M.N. M. Sidek, N.H. Hashim, S.R. Rosseli, M. R. M. Nor, S. Ismail, H. M. Saman, M. F. Arshad, A. Alisibramulisi and F. Zainudin, Utilization of Palm Oil Fuel Ash (POFA) as Cement Replacement by Using Powder and Liquidation Technique, AIP Conference Proceedings 2020.
4. Jonida Pone, Ahmed Ash, John Kamau and Fraser Hyndman studied on “Palm Oil Fuel Ash as A Cement Replacement in Concrete” (2018). Jonida Pone, Ahmed Ash, John Kamau and Fraser Hyndman studied on “Palm Oil Fuel Ash as A Cement Replacement in Concrete” (2018).
5. Hussein M Hamada, Gul Ahmed Jokhio, Fadzil Mat Yahaya and Ali M Humada, studied on “Properties of fresh and hardened sustainable concrete due to the use of palm oil fuel ash as cement replacement” (2018).
6. A Study on Strength of Concrete with Partial Replacement of Cement with Quarry Dust and Metakaolin A.V.S.Sai. Kumar1, Krishna Rao B2
7. Strength and durability properties of high-performance concrete incorporating high reactivity metakaolinBB Patil, PD Kumbhar.
8. Beulah M. Asst Professor, Prahallada M.C. Professor, Effect of Replacement of Cement by Metakaolin on the Properties of High-Performance Concrete Subjected to Hydrochloric Acid Attack.
9. Sanjay N. Patil, Anil K. Gupta, Subhash S. Deshpande examined the Metakaolin – Pozzolanic Material for Cement in High Strength Concrete.
10. Vikas Srivastava, Rakesh Kumar and V.C Agarwal 201 Effect on mechanical properties of Mold Metakaolin inchsalon incranes the compere til find ant hul mengs ant modules of elasticity of conte consider thai slightly compromised.
11. Aiswarya, S. prince Aralraj G. Dilip C is 2013 revi Metakaolin as supplementary censentations material in concrete.

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY

| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

www.ijmrset.com