International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

ASSESSMENT OF THE MECHANICAL PROPERTIES OF HYDROPHOBIC CONCRETE BY ADDING ALTERNATIVE CEMENTITIOUS MATERIALS

A. VISHNU[1], V. SABITHA[2], S. SAKTHI VIKNESH[2], S. SOWMIYA[2]

[1]Assistant Professor II, Department of Civil Engineering, Kumaraguru College of Technology, Coimbatore-641049, India.
[2]Students, Department of Civil Engineering, Kumaraguru College of Technology, Coimbatore-641049, India.

ABSTRACT:

This paper is dedicated for the Research on the improvement of the mechanical properties of Hydrophobic concrete by the Addition of cementitious mixture of Diatomaceous Earth Powder(DE), Fly ash Class-C (FA) and Hydrated Lime(CaO) as alternatives for Cement at a varying Dosage of 15% [DE-7.5%, FA-5.25%,CaO-2.25%] and 20% [DE-10%, FA-7%,CaO-3%] or simply in a ratio of 10:7:3 by considering the cementitious constituents present in each materials . To enhance the mechanical strength the Hooke ended steel fibre with an Aspect Ratio of 80 (L/D) was introduced in the concrete by 1% volume fraction as recommended by IRC SP-46:2013. The Mechanical Strength tests like Compressive Strength, Tensile Strength and Flexural Strength tests were conducted at 28 days and the results were analysed and found the Optimum Dosage as 15% replacement with cement and addition of Steel fibre in 1% Volume Fraction.

Keyword: Hydrophobic Concrete, Steel fibre, Mechanical strength, Diatomaceous Earth

INTRODUCTION:

Concrete is one of the most widely used construction material, but in specified locations the durability of the concrete faces a downfall due the moisture penetration, leading to strength reduction and long-term deterioration. To overcome this issue, the Hydrophobic modifications are introduced in concrete which limits the water penetration into the capillary pores of the concrete by the same time it reduces the Mechanical strength of the concrete as Hydration reaction on Cement gets disturbed [$2C_3S + 6H_2O = C_3S_2H_3 + 3Ca\ (OH)_2$] , Here the $C_3S_2H_3 + 3Ca\ (OH)_2$ formation is reduced due to reduced water availability , resulting in lower strength development.

Hydrophobic nature can be incorporated in concrete by two types of modification. They are Surface and Bulk modification. In Surface modification the hydrophobic agents like Silanes (SiH_4), Siloxanes, Emulsions and fatty acids are get coated to the surface of the concrete, making the surface alone Hydrophobic. In this case the Strength of the concrete is maintained as there is no interior modification of the concrete but if the outer layer gets damaged due to any other factors the concrete becomes Hydrophilic in nature. In Bulk modification the Hydrophobic Admixtures are added directly into the concrete while mixing is done and this have the impact on the strength of the concrete, to overcome this strength reduction in concrete the Steel fibre is introduced in 1% of the Volume fraction.

The production of cement, a key component of concrete, contributes significantly to carbon dioxide (CO_2) emissions, leading to environmental concerns. To mitigate these issues, researchers have explored the use of supplementary cementitious materials (SCMs) such as Diatomaceous Earth (DE), Class C Fly Ash (FA-C), and Hydrated Lime ($Ca\ (OH)_2$) as partial cement replacements to enhance concrete properties while reducing its environmental impact. Diatomaceous Earth (DE) or Diatomite is a naturally occurring siliceous material composed mainly of amorphous silica (SiO_2), derived from fossilized diatoms. The crumbles fine white or half white powder of particle size ranging from more than 3mm to less than 1μm of Diatomite is used as a filter aid and mild abrasives in the products including metal polishes and toothpastes. Due to its high pozzolanic activity, DE can react with calcium hydroxide ($Ca\ (OH)_2$) to form additional calcium silicate hydrate (C-S-H) gel, thereby improving concrete strength and durability. However, DE alone may not provide sufficient early strength, necessitating the incorporation of other reactive materials.

Class C Fly Ash (FA-C), a byproduct of coal combustion, is a highly reactive pozzolan that contains significant amounts of calcium oxide (CaO), silica (SiO_2), and alumina (Al_2O_3). Unlike Class F Fly Ash, FA-C has self-cementing properties, contributing to early strength development while enhancing long-term durability. The presence of CaO in FA-C also facilitates a stronger pozzolanic reaction when combined with DE.

MATERIALS AND METHODS :

To make the concrete more sustainable the PPC cement (Ramco Brand) is used as Binder, river sand is completely replaced with the m-sand and coarse aggregate of size 20mm is used. For incorporating the Hydrophobic character Dr. Fixit Water Proofing admixture was introduced in the mentioned dosage.

The diatomaceous Earth powder was added in a varied dose of 0%,7.5 and 10% of Cement. Similarly, along with Diatomaceous Earth, Fly ash of varying dosage (0%, 5.25% and 7%) and Hydrated lime of varying dosage (0%, 2.25% and 3%) was also added.

Chemical composition of cement and Diatomaceous Earth **Table 1**

Constituents /Materials	SiO_2(%)	Al_2O_3(%)	Fe_2O_3(%)	CaO (%)	MgO (%)	Alkalis (%)
Cement	25 - 35	4 – 10	2 - 6	50 - 60	0.5 – 2	0.5 – 1.5
Diatomaceous Earth	70 – 90	3 – 10	1 - 5	0.5 - 5	0.5 - 2	1 - 5

Comparing River sand and M-sand **Table 2**

Constituents /Materials	SiO_2(%)	Al_2O_3(%)	Fe_2O_3(%)	CaO (%)	MgO (%)	Na_2O & K_2O (%)	Silt & clay content (%)
River sand	80 - 90	2 – 4	1 - 3	0.5 - 2	0.5 – 1.5	0.5 - 1.5	2 - 8
m-sand	85 - 95	1 - 3	0.5 - 2	0.5 – 1.5	0.2 - 1	0.2 - 1	< 2

On comparing the Cement and Diatomaceous Earth the Calcium Oxide (CaO) content in lower in Diatomaceous Earth to make it even the Fly ash with 15 – 35% CaO Content and the Hydrated lime is added.

Composition of Materials in Different Mixes **Table 3**

Replacement (%)	Diatomaceous Earth (%)	fly ash (%)	Hydrated Lime (%)	Cement (%)
0	0	0	0	100
15	7.5	5.25	2.25	85
20	10	7	3	80

Cube (150*150 mm), Cylinder (300*100 mm) and Prism (500*100*100 mm) were casted for all the three different mixes and the Compression, tension and Flexure tests were performed after 28 days of curing.

The quantity of stell fibre in the concrete is estimated by using the IRC: SP:46-2013 (Clause 4.5.7, Table-3)

[Dosage of Steel fibre in kg/m^3 = 10*(fibre volume in %) * (specific gravity of Fibre material)]

Material	Length (mm)	Diameter (mm)	Aspect Ratio (L/D)	Nature	State	Specific Gravity	% Volume fraction	Quantity (kg/m^3)
Steel Fibre	60	0.75	80	Hook-ended	Recycled	7.85	1	80

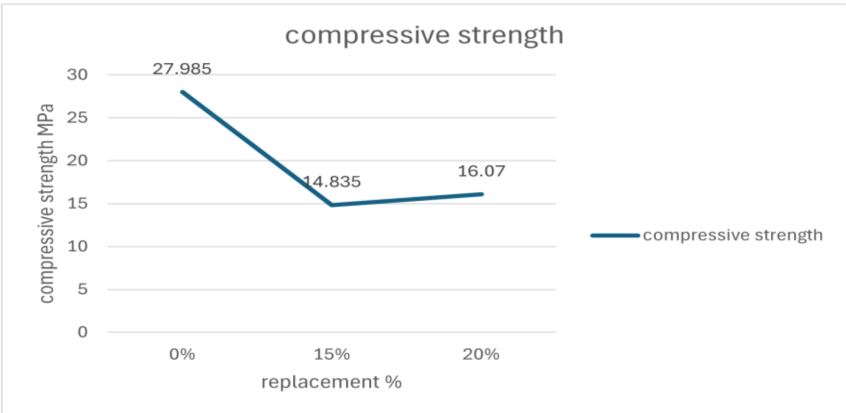
Physical Properties of Steel Fibre **Table 4**

TESTING AND ANALYSIS :

To check for the effects of the added cementitious materials (DE, FA, CaO) and Steel fibre in the concrete in its hardened state, the tests for the mechanical strength (Compression, Tension and Flexure) were conducted after 28 days of curing, the results of the strength tests are listed and analysed for finding the Optimum dosage of the cementitious materials.

1.1 COMPRESSIVE STRENGTH TEST

Fig 1 – Compressive strength changes



Compressive Strength is used to determine the Load Bearing Capacity of the structure. The primary objective of this test is to determine the compressive strength of the concrete cube of size 150mm*150mm*150mm which is prepared using PPC cement, m-sand and with partial replacement of cement with various doses(0%, 15% and 20%) of Diatomite(DE), Fly ash(FA) and Lime(CaO) in the ratio of 10:7:3 incorporated with Steel fibre of Aspect ratio 80 in 1% Volume fraction and the Hydrophobic admixture. The test was conducted in the compressive Testing Machine (CTM) of Strength of Materials Laboratory in Kumaraguru College of Technology.

The concrete mix was designed as per IS 10262:2019 standards for M40 Grade and the testing results showed that the compressive strength decreases initially till 15%(DE-7.5%, FA-5.25%, CaO-2.25%) and starts increasing gradually when reaching 20%(DE-10%, FA-7%, CaO-3%).The steel fibre addiction doesn't gave the expected impact in the compressive strength in the concrete, it may due to the lack of Hydration process in the cube due to the addition of hydrophobic agent and the accumulation of the fibre at a particular area (i.e.) the uneven distribution of the fibre.

Fig 2 – Compression Test

1.2 TENSILE STRENGTH TEST

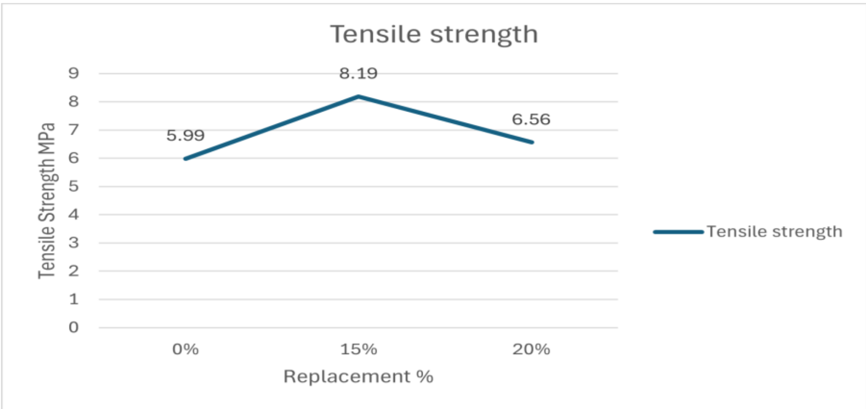


Fig 3 – Tensile strength changes

Tensile strength is used to determines the material's resistance to cracking and failure under tensile stress. The cylinder specimen of 300mm*100mm was used for this test. Introduction of hydrophobic agents and alternative cementitious materials, such as diatomaceous earth (DE), fly ash (FA), and hydrated lime (CaO), influences the hydration process and microstructure, thereby affecting tensile properties. From the experimental results, the control concrete exhibited the lowest tensile strength, while the 15% replacement mix (DE-7.5%, FA-5.25%, CaO-2.25%) showed an improvement in tensile strength, reaching 8.19 N/mm² compared to 5.99 N/mm² in the control mix. This increase can be attributed to the pozzolanic reaction of fly ash and diatomaceous earth, which refines the pore structure and enhances bonding between aggregates and the cementitious matrix. However, at a 20% replacement level (DE-10%, FA-7%, CaO-3%), a decrease in tensile strength was observed, indicating that excessive replacement might weaken the binding capacity and reduce overall cohesion within the mix.

The presence of Hooke-ended steel fibres at a 1% volume fraction further improved tensile strength by enhancing crack resistance and load transfer across microcracks. The fibres bridge the cracks, delaying their propagation and improving ductility. The addition of hydrophobic agents, while reducing permeability, may also slightly alter early-age hydration, which could influence tensile strength development. Moreover, chemical interactions between calcium hydroxide and alternative cementitious materials contribute to the densification of the calcium silicate hydrate (C-S-H) phase, which is primarily responsible for tensile strength.

Fig 4 – Tensile Test

1.3 FLEXURAL STRENGTH TEST

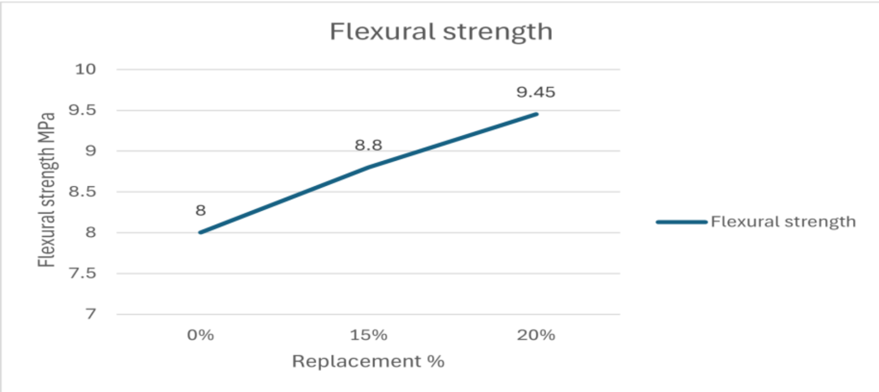
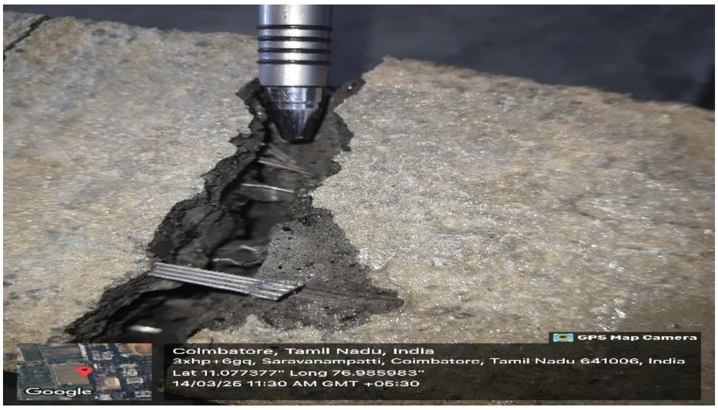


Fig 5 – Flexural strength changes

Flexural strength is a critical property that determines the ability of concrete to resist bending and cracking under load. In this study, the replacement of cement with diatomaceous earth (DE), fly ash (FA), and hydrated lime (CaO) influenced the flexural behaviour of hydrophobic concrete. The control mix (C) exhibited the lowest flexural strength of 8.0 N/mm², while the 15% replacement mix (DE-7.5%, FA-5.25%, CaO-2.25%) showed an improved flexural strength of 8.8 N/mm². This enhancement is primarily attributed to the pozzolanic activity of fly ash and diatomaceous earth, which refines the pore structure and improves the interfacial transition zone (ITZ) between the aggregates and the cementitious matrix. Additionally, the inclusion of 1% Hooke-ended steel fibres significantly contributed to increased flexural capacity by bridging cracks and improving load distribution, delaying crack propagation and enhancing ductility.

At 20% replacement (DE-10%, FA-7%, CaO-3%), the flexural strength further increased to 9.45 N/mm², indicating that a higher percentage of alternative cementitious materials contributes to better flexural performance. This improvement is linked to the densification of the concrete matrix due to secondary hydration reactions and the optimized packing of fine particles, leading to enhanced bonding between components. However, while hydrophobic agents help in reducing moisture ingress, excessive hydrophobic modification could potentially interfere with hydration, affecting strength development. The results suggest that steel fibre reinforcement and optimized replacement ratios are essential for achieving an ideal balance between hydrophobicity, flexural strength, and durability, making hydrophobic concrete a viable alternative for structural applications requiring superior crack resistance.

Fig 6 – Flexural test specimen



CONCLUSION :

From the graph obtained after the completion of all test procedures the Compressive Strength Peaks at the control (C) and decreases at 15%, then slightly increases at 20%, Tensile Strength increases at 15% and then decreases at 20%, Flexural Strength increases consistently from control to 20%.

In the Optimum Dosage analysis, it is found that 15% shows the highest tensile strength.20% shows an increasing trend in flexural strength. Compressive strength is highest at control (C), but 15% performs better than 20%. Finally, the 15% replacement of cement with Diatomite (DE), Fly Ash (FA) and Lime (CaO) was found as the Optimum dosage, as it balanced Compressive, Tensile and Flexural strength without significant strength losses.

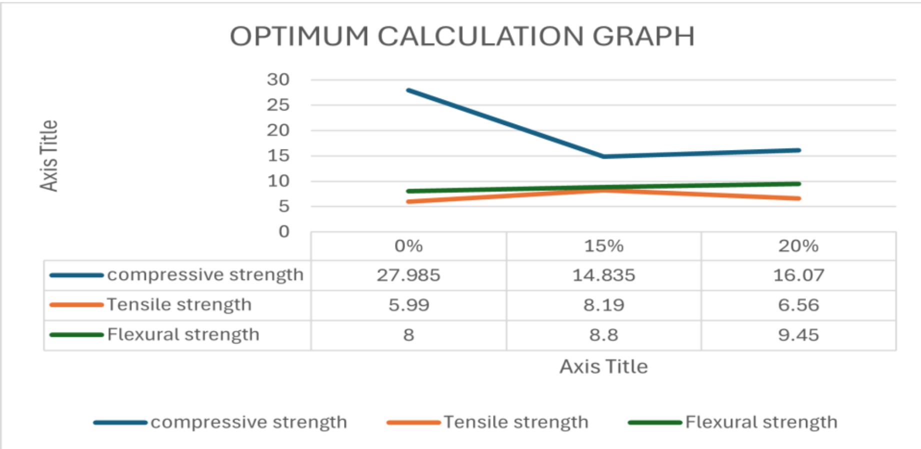


Fig 7 – Optimum Dosage Analysis Graph

REFERENCES :

1.Neha Sharma and Prashant Sharma, Effect of hydrophobic agent in cement and concrete: A Review, 2021 IOP Conf. Ser.: Mater. Sci. Eng. 1116012175

2 Rajesh Kumar Dubey, A Review on the Effect of Hydrophobic Agents on the Mortar and Concrete

3. Japneet Sidhu, Pardeep Kumar, Robin Bhardwaj, Vinay Kumar, Experimental Investigation on Hydrophobic Treatment of Cement Concrete with Organ silane Based Compound.

4. Cecielle N. Dacuan, Virgilio Y. Abellana, Hana Astri, R. Canseco, Minerva Q. Cañete, Hydrophobic Polyurethane Coating against Corrosion of Reinforced Concrete Structures Exposed to Marine Environment.

5. Mohammad Farid Alvansazyazdi, Fabricio Alvarez-Rea, Jhon Pinto-Montoya, Majid Khorami, Pablo M. Bonilla-Valladares, Alexis Debut and Mahdi Feizbahr, Evaluating the Influence of Hydrophobic Nano-Silica on Cement Mixtures for Corrosion-Resistant Concrete in Green Building and Sustainable Urban Development.

6. Makhmud Kharun, Armin Ehsani, Shahin Nasimi, Tesfaldet H. Gebre, Properties and behavior of light hydrophobic concrete

7. Japneet Sidhu and Pardeep Kumar, Department of Civil Engineering, National Institute of Technology, Hamirpur, H.P., India, Comprehensive review on hydrophobic modification of concrete: Progress and perspectives

8. Joseph Gnanaraj S and Vasugi K, A comprehensive review of hydrophobic concrete:surface and bulk modifications for enhancing corrosion resistance, 2024 Eng. Res. Express 6 032101

9. S. W. Muzenski, I. Flores-Vivian, and K. Sobolev Department of Civil & Environmental Engineering, University of Wisconsin-Milwaukee, The Development of Hydrophobic and Superhydrophobic Cementitious Composites.

10. Mazen J. Al-Kheetan, Mujib M. Rahman, Denis A.Chamberlain, Development of hydrophobic concrete by adding dual-crystalline admixture at mixing stage

11. Mazen J. Al-Kheetan, Mu'ath Al-Tarawneh1, Seyed Hamidreza Ghaffar2, Mehdi Chougan, Yazeed S. Jweihan1, Mujib M. Rahman, Resistance of hydrophobic concrete with different moisture contents to advanced freeze thaw cycles

12. Guo Li, Chunhua Fan, Yajun Lv and Fujun Fan, Effect of Hydrophobic Treatments on Improving the Salt Frost Resistance of Concrete.

13.M. Medeiros, P. Helene, Efficacy of surface hydrophobic agents in reducing water and chloride ion penetration in concrete.

14. Hong S. Wong, Robert Barakat, Abdulla Alhilali, Mohamed Saleh, Christopher R. Cheeseman, Department of Civil and Environmental Engineering, Hydrophobic concrete using wastepaper sludge ash, Imperial College London, SW7 2AZ, UK

15. by Vinh T. N. Dao, Peter F. Dux, Peter H. Morris, and Alan H. Carse, Performance of Permeability-Reducing Admixtures in Marine Concrete Structures

16. Rosa Di Mundo, Claudia Labianca, Giuseppe Carbone and Michele Notarnicola, Recent Advances in Hydrophobic and Icephobic Surface Treatments of Concrete

17. M M Rahman CEng MICE MICHT, D.A Chamberlain 2 FICE, The Performance of Crystalline Hydrophobic in Wet Concrete Protection

18. T. Büttner and M. Raupach, Institute of building materials research, ibac, Aachen University, Germany, Durability of Hydrophobic Treatments on Concrete Results from Laboratory Tests

19. O. Misnikov, Department of Geotechnology and Peat Production, Tver State Technical University, Russian Federation, Scientific basis of a new method for hydrophobic modification of mineral binders using peat products.

20. IS 456:2000 – Plain and Reinforced concrete – Code for practice

21. IS 10262:2019 – Guidelines for concrete mix design proportioning

22. IRC SP-46:2013 – Guidelines for design and construction of fibre reinforced concrete pavements.