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# SUSTAINABLE CONCRETE MADE WITH SEAWATER, METAKAOLIN AND FLY ASH

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*Abstract :* The research investigates the use of seawater as both a mixing and curing agent in M30 grade concrete, combined with the partial replacement of cement by fly ash and metakaolin. Specifically, the concrete specimens were prepared with varying proportions of fly ash (30% by weight of cement) and metakaolin (5%, 10%, and 15% by weight of cement). The seawater was sourced locally from the marine environment, replacing the conventional freshwater typically used in concrete production. Comprehensive testing procedures were employed to evaluate the mechanical properties of these concrete mixtures, focusing on key parameters such as compressive strength and flexural strength. The experimental results were then compared with those of conventional concrete mixes to assess the effectiveness of these sustainable alternatives. The findings from this research are quite promising. They suggest that utilizing seawater, along with fly ash and metakaolin, can enhance the mechanical properties of concrete. This approach not only has the potential to reduce the environmental impact of concrete production but also offers a way to conserve freshwater resources. Such innovative methods could be transformative for the construction industry, promoting eco-friendly practices and helping to address some of the environmental challenges we face today. The study provides valuable insights into the feasibility and practicality of implementing these sustainable techniques in real-world construction projects.

***Index Terms: Alternative materials, Seawater, Partial replacement, Metakaolin, Flyash, Compressive strength, Flexural strength, supplementary cementitious materials, Eco-friendly, Environmental impact***

## I. INTRODUCTION

Concrete is the most extensively used construction material in the world, second only to water in terms of consumption[1]. Most of the cementitious binders used in concrete are based on Portland cement clinker, whose manufacture is an energy-intensive process that also generates significant $CO_2$ emissions. These emissions primarily result from the release of $CO_2$ from limestone during the pyro-processing of clinker. To reduce energy consumption, $CO_2$ emissions, and increase production efficiency, cement plants produce blended cements incorporating supplementary cementitious materials such as metakaolin, silica fume, natural pozzolan, fly ash, and limestone.

Metakaolin (MK) has been extensively studied in recent years due to its high pozzolanic properties[2-5]. Unlike other pozzolans, metakaolin is a primary product rather than a secondary product or by-product. It is produced by the dehydroxylation of kaolin precursor upon heating within a temperature range of 700–800 °C[6,7]. The raw material for metakaolin ($Al_2Si_2O_7$) is kaolin. When metakaolin reacts with calcium hydroxide ($Ca(OH)_2$), it produces calcium silicate hydrate (C–S–H) gel at ambient temperature and reacts with calcium hydroxide to form alumina-containing phases, including $C_4AH_{13}$, $C_2ASH_8$, and $C_3AH_6$[8,9]. Larbi[10] demonstrated that the use of appropriate concentrations of metakaolin can virtually eliminate free lime from the cement matrix.

Metakaolin is increasingly used to produce high-strength, high-performance concrete with enhanced durability. Extensive research has been reported in the literature concerning various properties of metakaolin paste and concrete, such as porosity, pore size distribution, pozzolanic reaction, and the compressive strength and durability of metakaolin concrete[11-13].

## II. MATERIALS AND METHODS

Ordinary Portland Cement of 53 grade was used confirming to IS: 12269 – 1987 and the specific gravity of cement was found to be 3.13. Locally available River sand having bulk density of 1.71 kg/m3 was used with a specific gravity is 2.65. The Fineness modulus of river sand is 2.44. The bulk density of Manufactured sand was 1.75 kg/m3 , specific gravity and fineness modulus was found to be 2.73 and 2.87, respectively. Crushed angular aggregate with maximum grain size of 20 mm was used with a bulk density of 1.38 kg/m3 . The specific gravity and fineness modulus of coarse aggregate was 2.82 and 7 respectively. Metakaolin is a dehydroxylated form of clay mineral kaolinite brought from Aastra Chemicals, Chennai, whose specific gravity was 2.26. In this study, freshwater and seawater are alternately used for curing and mixing. Seawater used in the project for mixing and curing was collected from Nagapattinam, Tamilnadu.

**III.MIX PROPORTIONS**

Concrete mixtures were prepared to study the effect of using seawater to mix and cure plain concrete. These mixtures were divided into four categories providing different combinations of using sea and fresh tap water in mixing and curing of concrete. These concrete categories were mixed and cured using fresh water (FF), mixed with seawater and cured with fresh water (SF), mixed with fresh water and cured with seawater (FS) and finally mixtures that are mixed and cured with seawater (SS). After 24 hours, all concrete specimens were cured at a temperature of 20°C. For reducing the harmful effect of seawater on concrete, mineral admixture such as metakaolin and fly ash were used in different proportions.

Concrete mix for M20 grade was designed as per the guidelines specified in IS 10262-2009 and IS 456- 2000 with a ratio of 1: 1.9: 3.2. For determining mechanical properties, eight different types of mixes were used as described in Table 1

**Table 1 Mix Designation and Combinations**

| S.No. | Mix Designation | Mix Combination |
|---|---|---|
| 1 | FSCC | Fresh water + 100% OPC |
| 2 | FSFA30MK5 | Fresh water + 30% FA + 5% MK |
| 3 | FSFA30MK10 | Fresh water + 30% FA + 10% MK |
| 4 | FSFA30MK15 | Fresh water + 30% FA + 15% MK |
| 5 | SFCC | Seawater + 100% OPC |
| 6 | SFFA30MK5 | Seawater + 30% FA + 5% MK |
| 7 | SFFA30MK10 | Seawater + 30% FA + 10% MK |
| 8 | SFFA30MK15 | Seawater + 30% FA + 15% MK |

**Table 2 Proportion of Mix with Flyash and Metakaolin**

| Specimen Name | C $Kg/m^3$ | M Sand $Kg/m^3$ | CA $Kg/m^3$ | FA $Kg/m^3$ | MK $Kg/m^3$ | Water Content $Kg/m^3$ | Mixing Water | Curing Water |
|---|---|---|---|---|---|---|---|---|
| CC | 345 | 701 | 1244 | - | - | 162 | FW | SW |
| | | | | | | | SW | FW |
| FA30&MK5 | 247 | 772 | 1093 | 114 | 19 | 161 | FW | SW |
| | | | | | | | SW | FW |
| FA30&MK10 | 228 | 771 | 1091 | 114 | 38 | 161 | FW | SW |
| | | | | | | | SW | FW |
| FA30&MK15 | 209 | 769 | 1088 | 114 | 57 | 161 | FW | SW |
| | | | | | | | SW | FW |

(Where,C = Cement, CA = Coarse Aggregate, FA = Fly ash, MK = Metakaolin)

Cube and prism specimens having sizes of 150 mm x 150mm x 150mm, and 700 mm x 150 mm x 150mm were used to evaluate the compressive and flexural strength respectively. A water to cement ratio of 0.35 and a chemical admixture dosage of 1.2% were fixed in all mixes with a cement content of 350kg/m3. The mix proportion of mix with Flyash and Metakaolin were presented in Table 2.

**IV RESULTS AND DISCUSSIONS**

**4.1 Compressive Strength**

The values obtained from the compressive test on cube at $7^{th}$ day and $28^{th}$ day were presented in the Table 3. Graphs were plotted for compressive strength vs curing period as shown in Fig. 2 and Fig. 3.. The formation of cracks on cubes after applying load is shown in Fig. 1.

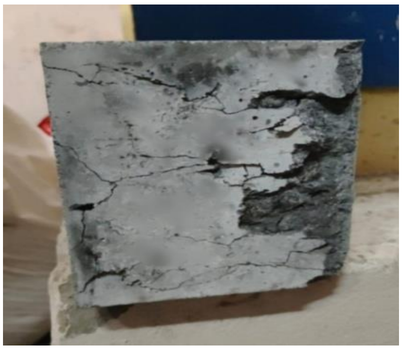

**Fig. 1 Cube after applying load**

**Table 3 Compressive strength of cubes at 7 & 28 days**

| % Mix | Mixing – FW<br>Curing – SW<br>In N/mm² | | Mixing – SW<br>Curing – FW<br>In N/mm² | |
|---|---|---|---|---|
| | 7 days | 28 days | 7 days | 28 days |
| Conventional Mix | 23.97 | 36.89 | 25.33 | 38.67 |
| FA 30% MK 5% | 25.78 | 39.56 | 26.67 | 40.89 |
| FA 30% MK 10% | 26.67 | 41.33 | 28.44 | 43.56 |
| FA 30% MK 15% | 24.89 | 40.89 | 27.56 | 42.22 |

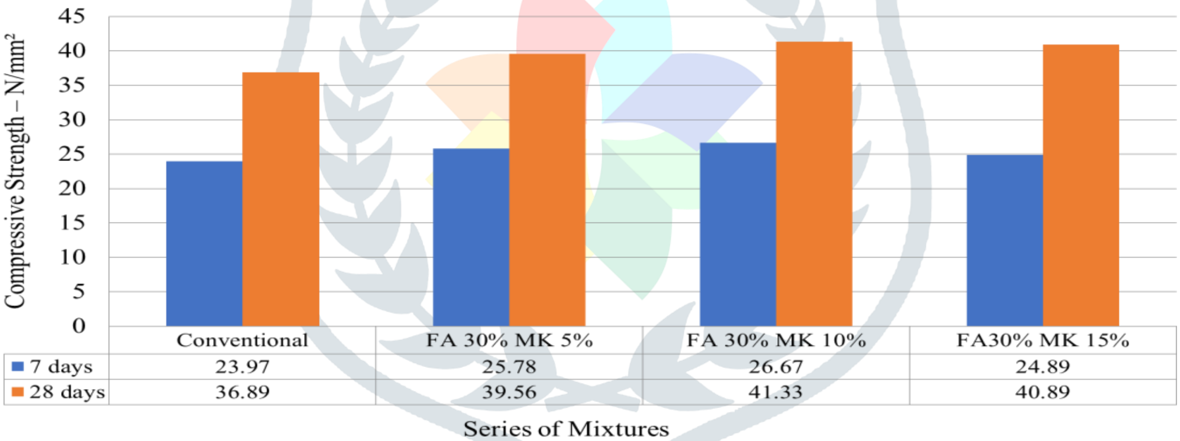


**Fig. 2 Compressive Strength of Cubes mixed with freshwater and cured inseawater**

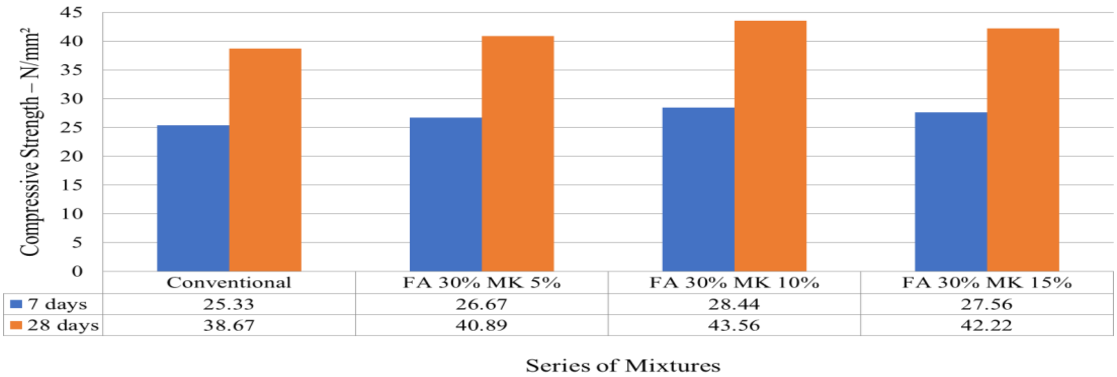


**Fig. 3 Compressive Strength of Cubes mixed with seawater and cured infreshwater**

The Fig. 4 & Fig.5 of the compressive strength of cubes shows that the cubes made of mix with 5% of Metakaolin and 30% of Fly ash shows better results than the other two mixes.

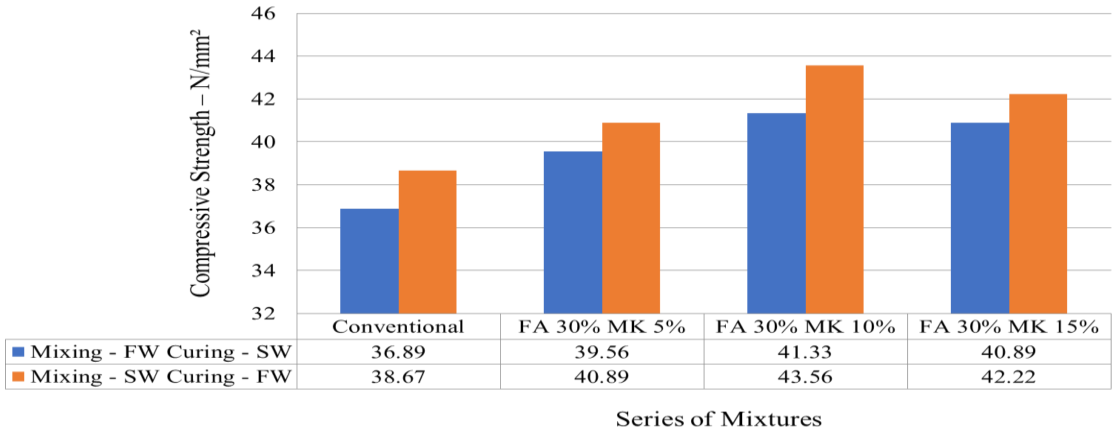


**Fig. 4 Compressive Strength of Cubes with alternative curing and mixing agents at28 days**

The Fig. 4 of the compressive strength of cubes which are mixed with sea water and cured in fresh water shows better results than the cubes mixed with fresh water and cured in seawater. It is also found that the cubes made of mix with 5% of Metakaolin and30% of Fly ash gives better results than the other two mixes.

### 4.2 Flexural Strength

The values obtained from the flexural strength on the 28$^{th}$ day were presented in Table 4. Graphs were plotted for flexural strength vs curing period. The formation of cracks on prisms after applying load in shown in Fig. 5.

**Fig. 5 Formation of cracks on prism under loading**

**Table 4 Flexural strength of prisms at 28 days**

| % Mix | Mixing – FW<br>Curing – SW<br>In N/mm² | Mixing – SW<br>Curing – FW<br>In N/mm² |
|---|---|---|
| Conventional Mix | 8.3 | 9.5 |
| FA 30% MK 5% | 8.6 | 10.3 |
| FA 30% MK 10% | 11.0 | 12.4 |
| FA 30% MK 15% | 9.7 | 11.2 |

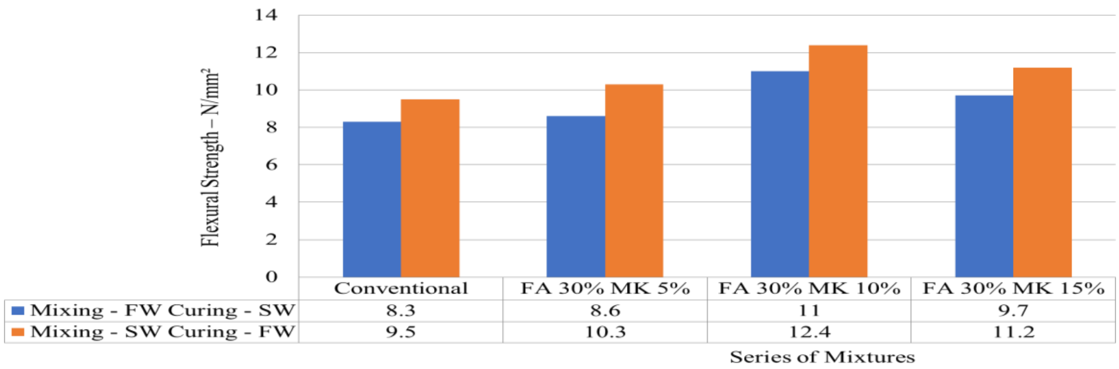


**Fig. 6 Flexural Strength of Prisms with alternative curing and mixing agents at 28days**

Fig.6 of the flexural strength of prisms which are mixed with sea water andcured in fresh water shows better results than the cubes mixed with fresh water and cured in seawater. It is also found that the cubes made of mix with 5% Metakaolin and 30% Fly ash give better results than the other two mixes.

### 4.3 Influence of Fly ash and Metakaolin

Pozzolanic reactions, crucial for improving concrete properties, occur between Metakaolin, Fly ash, and calcium hydroxide, produced during cement hydration. A blend of 10% Metakaolin and 30% Fly ash optimally enhances these reactions, densifying the concrete matrix and boosting strength. This mix strikes a balance, fostering efficient pozzolanic reactions without diluting cementitious properties excessively. The ratio of Metakaolin to Fly ash significantly impacts concrete characteristics. Lower Metakaolin content (5%) may hinder pozzolanic reactions, as insufficient pozzolanic material might be available to utilize the calcium hydroxide fully. Conversely, higher Metakaolin content (15%) alongside 30% Fly ash may lead to an imbalance, resulting in excess pozzolanic material relative to available calcium hydroxide. This disproportion may foster the formation of unreacted Metakaolin particles, compromising concrete strength.

In conclusion, concrete formulations with 10% Metakaolin and 30% Fly ash exhibit superior performance compared to mixes containing 5% and 15% Metakaolin alongside 30% Fly ash. This optimized blend achieves an ideal equilibrium of supplementary materials, facilitating efficient pozzolanic reactions, denser microstructure, and enhanced mechanical properties.

### 4.4 Effect of Seawater in Concrete

The choice of mixing agent greatly affects the hydration process and properties of concrete. Seawater introduces various ions and salts, like sodium and chloride, speeding up hydration reactions for rapid early strength development. In contrast, freshwater may lack essential ions, potentially slowing hydration and delaying strength gain. When curing concrete, seawater can cause leaching of calcium hydroxide, leading to reduced strength and durability over time. Freshwater provides a stable environment for proper hydration and bond formation, enhancing long-term strength and durability. In conclusion, while seawater accelerates early strength, freshwater offers controlled curing for optimized long-term performance. Careful consideration of mixing and curing agents is vital for tailored concrete performance in different construction applications.

### 4.5 Interpretation of Results

Using concrete mixes containing 30% Fly ash and Metakaolin, mixed with seawater during mixing and cured in freshwater, produced the highest compressive and flexural strengths compared to other mixtures. This highlights the importance of combining these materials and curing conditions for excellent concrete performance. The interaction of Fly ash and Metakaolin in the concrete, along with seawater and freshwater as mixing and curing agents, improved mechanical properties. These materials engage in pozzolanic reactions during cement hydration, forming extra cementitious compounds. This strengthens the concrete's microstructure, reducing porosity and enhancing strength. Furthermore, the utilization of seawater during mixing adds ions and salts to the concrete, speeding up hydration reactions and early strength development. Curing in freshwater creates a controlled environment for proper hydration and strong cementitious bond formation, ensuring long-term durability.

## V CONCLUSIONS

In this study, the key findings highlight the critical role of material selection and curing methods in customizing concrete formulations. Optimal combinations ofsupplementary materials, such as Fly ash and Metakaolin, alongside seawater for mixing and freshwater for curing, result in superior concrete performance. By fine-tuning these factors, the study demonstrates the potential to advance sustainable and high-performanceconcrete solutions in construction applications.

- The experimental investigation conducted in this study unveiled a promising avenue for enhancing the sustainability and mechanical properties of concrete. Bysubstituting cement with Metakaolin and Fly ash, and alternating between seawater and freshwater for mixing and curing, notable improvements were seen.
- Specifically, the concrete mixes that stood out for their superior performance werethose comprising 30% Fly ash and 10% Metakaolin. When combined with seawater during mixing and cured in freshwater, they displayed remarkable compressive and

flexural strengths.

- The optimized concrete mixtures offer improved sustainability and performance without compromising durability, making them suitable for various structural applications.
- This study provides significant solutions for reducing the environmental impact of concrete production in the construction industry. By substituting cement with Metakaolin and Fly ash, and using seawater and freshwater for mixing and curing, greenhouse gas emissions are reduced, and industrial byproducts are reused, aligning with circular economy principles.

## VI RECOMMENDATIONS FOR FUTURE RESEARCH

Further research is crucial for understanding the long-term durability and performance of sustainable concrete mixes. While initial findings are promising, real- world scenarios will test how these formulations hold up over time. Long-term studies can assess resistance to chemical degradation, freeze-thaw cycles, and structural integrity, providing insights into the reliability of sustainable concrete solutions.

Exploring alternative supplementary cementitious materials (SCMs) beyond Metakaolin and Fly ash is vital for advancing concrete sustainability. Various industrial byproducts and natural materials offer unique properties and environmental advantages, broadening the range of sustainable options for construction projects.

Investigating innovative curing methods is also key to enhancing concrete sustainability. While seawater and freshwater are steps forward, other techniques like steam curing and accelerated methods could further optimize performance and minimize environmental impact. Research in these areas will guide best practices and drive innovation in sustainable concrete production, supporting a resilient and environmentally conscious built environment for future generations.

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