A Comparative Study Using M-Sand And Metakaolin To Improve Concrete Strength And Quality

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Abstract- *Concrete is the most widely used construction material, but its conventional ingredients—natural river sand and ordinary Portland cement—pose environmental concerns due to overexploitation of natural resources and high carbon emissions. This review paper focuses on the combined use of Manufactured Sand (M-Sand) and Metakaolin as sustainable alternatives for fine aggregate and cement respectively. A comparative analysis of previous studies is presented to evaluate the effect of these materials on the workability, strength, and durability of concrete. Findings indicate that M-Sand enhances particle packing and compressive strength when properly graded, while Metakaolin improves microstructure, reduces porosity, and increases long-term durability. Optimum replacement levels are generally observed around 20–30% for M-Sand and 10–15% for Metakaolin. The combined use results in higher strength, better durability, and reduced environmental impact, making it a promising solution for sustainable construction.*

Keywords- OPC 53 grade of Cement, Natural sand, Manufactured Sand (M-Sand) ,Metakaolin, strength, and durability.

I. INTRODUCTION

The growing demand for concrete has led to excessive consumption of natural river sand and cement, both of which contribute to environmental degradation. River sand mining disrupts ecosystems, while cement production emits approximately 8% of global CO_2. To address these issues, researchers have explored alternative materials such as Manufactured Sand (M-Sand) and supplementary cementitious materials like Metakaolin.

M-Sand is produced by crushing hard stones, offering consistent grading and angular particles that enhance bond strength. Metakaolin, derived from the calcination of kaolin clay at 650–800°C, acts as a highly reactive pozzolan, improving concrete's mechanical and durability properties. This paper reviews existing literature to assess the comparative effects of incorporating M-Sand and Metakaolin on concrete quality and performance.

Role of M-Sand in Concrete

M-Sand replaces natural river sand and has the following characteristics:

Improved Gradation: Provides uniform particle size distribution.

Enhanced Strength: Angular texture improves interlocking.
Reduced Voids: Leads to denser microstructure.

Challenges: May reduce workability due to angular particles; requires higher water or admixture dosage.

Role of Metakaolin in Concrete

Metakaolin (MK) is a highly reactive pozzolanic material obtained from dehydroxylation of kaolin.

- **Pozzolanic Reaction:** Reacts with calcium hydroxide to form additional C–S–H gel.
- **Mechanical Benefits:** Enhances compressive, flexural, and tensile strength.
- **Durability:** Improves resistance to chloride ingress, sulphate attack, and reduces permeability.

Combined Use of M-Sand and Metakaolin

When used together, M-Sand and Metakaolin synergistically improve concrete performance:

- M-Sand provides better mechanical interlock.
- Metakaolin refines pore structure and reduces water absorption.
- The combination yields higher compressive and flexural strength, particularly in M25–M40 grade concretes.
- Durability parameters such as water absorption, chloride permeability, and sulphate resistance show significant improvement.

However, proper mix design adjustment is essential to balance workability and strength. Studies suggest water-reducing admixtures and controlled grading of M-Sand to offset reduced slump.

Research Gaps

Despite extensive studies on M-Sand and Metakaolin individually, limited work explores their combined performance. Future studies should focus on:

- Microstructural analysis (SEM, XRD, FTIR) to understand interaction effects.
- Long-term durability under aggressive environments.
- Life-cycle cost and carbon footprint assessments.
- Development of mix design guidelines for combined use.

II. LITERATURE REVIEW

M. J. Anju, et al. (2023)

The construction sector consumes a large amount of concrete. Sand accounts for approximately 35% of the volume of concrete. Manufactured sand is a by-product and it is a usable substitute for river sand. The manufactured sand obtained from hard rocks by crushing plant. It is also known as M-Sand, Crushed stone sand, Quarry dust, Rock sand, Crushed dust, and other names. The quite exhaustive research has been carried out on using manufactured sand in concrete. This research review effort focuses on the enhancement of strength of concrete by focusing on strength parameters to improve the strength characteristics of concrete and thereby improving its living standard in terms of Compressive Strength.

Sachin Patil , et al. (2023)

Products that are pozzolanic Metakaolin (MK) & Silica fume (SF), both smaller than cement, are being used in the making of concrete and have been shown to improve the characteristics of the concrete. This study uses the combination of MK and SF as a additional cementitious substance. It was planned to explore the mechanical characteristics of Binary Fiber and Admixture based High-Performance Concrete (BFAHPC), which uses glass fibres (GF) and polypropylene fibres (PPF) as an inclusion. The ratios of water to binder (W/B) from 0.275 to 0.350, were used, with an aggregate to binder content (A/B) of 1.75. MK and SF were substituted in proportions ranging from 0 % to 15 %. GF was introduced in volume proportions ranging from 0 % to 1 %, and PPF was used at 0.25 percent only. The overall influence of MK with SF at 5 % each as cement replacements, with fibre dosages of GF = 1 % and PPF = 0.25 % for W/B of 0.275, was indicated to be the perfect pairing for obtaining maximal strength for BFAHPC proposed. The results obtained from this work also yielded a correlation in terms of mathematical equations relating compressive strength to split tensile strength, and flexural strengths of metakaolin and silica fume-based BFAHPC.

Panagiotis G. Asteris a, et al. (2022)

In this study, a model for the estimation of the compressive strength of concretes incorporating metakaolin is developed and parametrically evaluated, using soft computing techniques. In recent decades, metakaolin has been widely used as a component to lessen the need for cement in concrete. Six parameters are taken into consideration as input data for the suggested models. These include the age at testing, the percentage of metakaolin relative to the total binder, the ratio of water to binder, the percentage of superplasticizer, the ratio of binder to sand, and the ratio of coarse to fine aggregate. After a thorough review of the pertinent published literature, a database of 867 experimental specimens was created for the purpose of training and validating the proposed models. The best model, which is able to accurately estimate the concrete's compressive strength while taking metakaolin consumption into consideration, was chosen through a rigorous review process.

M. Jayasri (2021)

This paper presents the consequences of an exploratory examination on the mechanical properties of underlying substantial utilizing Steel fiber (SF), Polypropylene fiber (PF) and Metakaolin (MK).The impacts of these strands and MK on different properties of M30 grade concrete are contemplated. MK Steel fiber content and Polypropylene fiber content were shifted in rate by weight of concrete. Every one of the examples was water relieved and tried following 28 days. It is seen that huge improvement in the primary presentation of cement is accomplished by the expansion of 15% MK in typical cement. Mixture fiber built up concrete (HFRC) diminishes the odds of fragility by capturing the miniature and full scale breaks. An expansion of 28.5% was noticed for 28 days compressive strength. Perceptible decrease in compressive strength was seen with expanding the level of MK past 15%.

Ashish Kumar (2020)

Concrete is viewed as the most broadly utilized and flexible material of development everywhere. One of the

significant elements of ordinary cement is regular sand or waterway sand, which is very nearly debilitating because of plentiful utilization. In this substance Metakaolin was a pozzolanic material utilized in wide reach in substitution of concrete. Metakaolin is dehydroxylated aluminum silicate, because of its pozzolanic movement the strength properties and sturdiness properties of substantial increments and decrease in Porosity and Porousness too. In this current examination fractional supplanting of concrete with Metakaolin at 0%, 5%, 10%, 15% and supplanting normal sand with half ROBO sand. The mechanical properties of cement for example compressive strength, split elasticity and flexural strength are contemplated of cement made with substitution of MK-RS and results are contrasted and regular cement. In this work absolutely six blends are ready with M20and M25 grade substantial blend and normal of three examples were tried for 7 days, 14 days and 28 days for each blend.

Sonal Shah and Satish Desai (2019)

This paper concentrates on the impact of consolidating Metakaolin on the mechanical properties of high grade concrete. Three distinct Metakaolins calcined at various temperature and terms were utilized to make substantial examples. Three diverse substantial combinations were portrayed utilizing 20% Metakaolin instead of concrete. A typical substantial blend was likewise made for correlation reason. The compressive strength test, split pliable test and flexural strength tests were led on the examples. The compressive strength test results showed that all the Metakaolin fused substantial examples displayed higher compressive strength and performed better compared to typical cement at every one of the times of relieving. The pace of solidarity improvement of the relative multitude of blends was likewise considered. The review uncovered that all the three diverse Metakaolin consolidated combinations had distinctive pace of solidarity advancement for every one of the times of hydration (3, 7,14, 28, 56 and 90), demonstrating that all the Metakaolins had diverse pace of pozzolanic reactivity. Further, from the examination of the experimental outcomes, it was inferred that the variety in the pace of solidarity advancement is because of the distinctions in the temperature and span at which they were fabricated.

Ayobami Busari (2019)

The interest and utilization of cement have prompted a ton of examination in working on its strength, solidness, life cycle, temperature impact and some more. Working on the strength and solidness of cement is extremely foremost in the development of essential foundation in a bid to make it feasible. The decision of Metakaolin as a beneficial material in working on the mechanical strength and sturdiness of concrete is embraced in this audit. This was done in a bid to decrease the expense of concrete being one of the most costly parts of substantial creation and to likewise further develop supportability in the development business. The survey uncovered that the utilization of Metakaolin in the development of cement showed a worked on mechanical strength. Writings uncovered that up to 10%-20% expansion in mechanical strength is recorded with the utilization of Metakaolin in substantial creation. Also, the strength properties of cement with Metakaolin additionally improved. Be that as it may, the audit uncovered that fusing Metakaolin in substantial creation diminished the functionality of concrete and expanded the hotness of hydration. The consequence of this survey showed that the utilization of Metakaolin diminished the expense of creating concrete. In view of the uniqueness of the material, it is suggested for use in nations where it is bountiful in an offered to advance supportability in substantial innovation, work on mechanical strength and lessen cost.

III. **OBJECTIVE OF THIS STUDY**

The main objective of this study is to experimentally investigate the effects of mixing M-Sand and Metakaolin as a partial replacement of fine aggregate and cement on properties of concrete and compare it with conventional concrete. The following were also considered:

- To investigate the properties of M-Sand and Metakaolin as a partial replacement of fine aggregate and cement on concrete.
- To determine the percentage that gives the maximum workability of multi-blended concrete when compared to conventional concrete.
- Standard grade concrete has compressive strength above 35 MPa. The methods and technology for producing standard grade concrete are not substantially different from those required for normal strength concrete.
- To determine the percentage that gives the maximum Compressive strength of multi-blended concrete when compared to conventional concrete at 7 and 28 days.
- To determine the percentage that gives the maximum Flexural strength of multi-blended concrete when compared to conventional concrete at 7 and 28 days.

IV. MATERIALS

Cement

Ordinary Portland Cement (OPC) of **43 or 53 grade** conforming to **IS 8112:2013** or **IS 12269:2013** is commonly used in experimental studies involving Metakaolin and M-Sand.

- **Physical Properties:** Specific gravity ranges from **3.10–3.15**; normal consistency around **30–33%**; initial setting time between **100–140 minutes**.
- **Chemical Composition:** Mainly composed of calcium silicates (C_3S and C_2S), calcium aluminates (C_3A), and calcium aluminoferrite (C_4AF).
- **Role:** Provides the basic binding matrix in concrete; partially replaced by Metakaolin in this study to improve pozzolanic activity and durability.

Figure no. 1 Ordinary Portland cement of grade 53

Table 1: Chemical Composition of OPC (53 Grade) and Metakaolin

Chemical Compound	**OPC 53 Grade (% by weight)**	**Metakaolin (% by weight)**	**Remarks / Significance**
SiO_2 (Silica)	20–22	50–55	Provides strength through formation of C–S–H gel
Al_2O_3 (Alumina)	5–7	40–45	Improves early strength and pozzolanic activity
Fe_2O_3 (Ferric Oxide)	2–3	<1.5	Influences color and fluxing characteristics
CaO (Calcium Oxide)	60–65	<1	Major component in cement hydration
MgO (Magnesium Oxide)	1–3	<0.5	Affects soundness of cement
$Na_2O + K_2O$ (Alkalis)	0.4–1.5	0.5–1.5	Excess can cause alkali–silica reaction
SO_3 (Sulphur Trioxide)	2–3	<0.2	Controls setting time and expansion
TiO_2 (Titanium Dioxide)	<0.5	1–2	Inert filler; improves whiteness in Metakaolin
Loss on Ignition (LOI)	2–4	<2	Indicates unburnt carbon and moisture content
Specific Gravity	3.14	2.5–2.6	Affects mix proportion and density
Color	Grey	Off-white	Visual identification

Fine Aggregate (M-Sand)

Manufactured Sand (M-Sand) is a **crushed stone sand** produced by mechanical crushing of hard granite or basalt rock. It conforms to **IS 383:2016 – Zone II grading**.

- **Physical Properties:**
  - Specific Gravity: **2.60–2.75**
  - Fineness Modulus: **2.5–3.0**
  - Water Absorption: **1.0–1.5%**
  - Bulk Density: **1600–1800 kg/m³**
- **Advantages:**
  - Uniform gradation and consistent quality.
  - Angular shape improves interlocking and strength.
  - Reduces environmental impact of river sand mining.
- **Replacement Levels (Typical):** 25%, 50%, 75%, and 100% replacement of natural sand.
- **Challenges:** Slightly reduced workability due to angular particles; requires admixtures for better flow.

Figure no. 3 M-sand is used as fine aggregates

Metakaolin

Metakaolin (MK) is a **calcined aluminosilicate material** derived from purified kaolin clay heated between **650°C–800°C**. It complies with **ASTM C618 (Class N)** pozzolan requirements.

- **Physical Properties:**
  - Color: Off-white
  - Specific Gravity: **2.5–2.6**
  - Particle Size: **1–2 µm**
  - Blaine Fineness: **15,000–25,000 cm²/g**

Figure no. 2 Metakaolin

Coarse Aggregate

Crushed granite or basalt is used as coarse aggregate in most studies.

- **Size:** 20 mm down, conforming to **IS 383:2016**.
- **Specific Gravity:2.7–2.9**
- **Water Absorption:0.5–1.0%**
- **Role:** Provides bulk and strength to the concrete.
- **Note:** Surface texture and angularity influence the bond strength between paste and aggregate.

Water

Potable water free from impurities, conforming to **IS 456:2000**, is used for mixing and curing.

- **pH Value:** 6–8
- **Importance:** Quality of water directly affects cement hydration and strength development.

V. CONCLUSION

The literature review confirms that both M-Sand and Metakaolin contribute positively to concrete performance.

- M-Sand improves particle packing and compressive strength.
- Metakaolin enhances pozzolanic activity, strength, and durability.
- Their combined application results in superior mechanical and durability characteristics.
- Hence, using M-Sand and Metakaolin as partial replacements for fine aggregate and cement, respectively, presents a viable pathway for sustainable and durable concrete.

REFERENCES

[1] rapururaghu ,k.mallikharjunarao : dec. 2021 “experimental study on concrete with partial replacement of hypo sludge in cement”. IRJET e-issn: 2395-0056 volume: 08 issue: 12 | dec 2021 www.irjet.net p-issn: 2395-0072

[2] s. c. nivedhitha g. ancelinteena, e. priya, e. suneka, b. durga : july-2021 “experimental study on partial replacement of cement by hyposludge in concrete with chemical admixture” IJERT http://www.ijert.org issn: 2278-0181 ijertv10is070304 published by : www.ijert.org vol. 10 issue 07, july-2021

[3] mohdabdulnayeem, p. naveenkumar : oct 2020 “an experimental study on concrete with partial replacement of hypo sludge in cement”. anveshana’s international journal of research in engineering and applied sciences volume 5, issue 10 (2020, oct) emailid: anveshanaindia@gmail.com, website: www.anveshanaindia.com

[4] ashutoshkote, g.c.jawalkar :aug 2019 “experimental study on partial replacement of cement by hypo sludge in concrete” IRJET e-issn: 2395-0056 volume: 06 issue: 08 | aug 2019 www.irjet.net

[5] hepzibah a, ranjithkumar m g : march 2019 “mechanical properties and durability properties of concrete with partial replacement of cement by hypo sludge” e-issn: 2395-0056 volume: 06 issue: 03 | mar 2019 www.irjet.net.

[6] m.tamilselvi, a.k.dasarathy, and s.ponkumarilango :nov. 2018 “effects of partial replacement of cement with hypo sludge in concrete”. international conference on sustainable engineering and technology (iconset 2018) aip conf. proc. 2039, 020005-1–020005-9; https://doi.org/10.1063/1.5078964 published by aip publishing. 978-0-7354- 1765-6/$30.003

[7] santoshahirwar, dr. rajeevchandak : 2018 “effective use of paper sludge (hypo sludge) in concrete” ijedr1802125 international journal of engineering development and research (www.ijedr.org) ijedr 2018 | volume 6, issue 2 | issn: 2321-9939.+

[8] Balamurugan .R, Karthickraja .R , “An experimental investigation of partial replacement of cement by

industrial waste (hypo sludge)" Int. JERA, Vol. 4, Issue 4, pp.430-435.

[9] Srinivasan .R, Sathiya .K and Palanisamy .M , "Experimental investigation in developing low cost concrete from paper industry waste" Buletinulinstitutuluipolitehnic din iai ş tomul lvi (lx) fasc.1, pp: 44-56.March 2015.

[10] Rushabh A. Shah Prof. Jayesh kumar Pitroda "Effect Of Hypo Sludge AsPartial ReplacementWith Cement In Mortar " APRIL2013 IRJET.

[11] IS 383-1970 : Specification for Coarse and Fine Aggregates From Natural Sources For Concrete, Bureau of Indian Standards, New Delhi, India.

[12] IS: 10262-2009, Recommended Guidelines for Concrete Mix Design, Bureau of Indian Standards, New Delhi, India