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Experimental Investigation on high performance concrete using metakaolin

Chandur Nikhitha[1], P. Suresh Chandra Babu[2], B. Sudharshan Reddy[3]

[1]M.Tech Student, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India.

[2]Assistant Professor, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India.

[3]Professor, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, Telangana, India.

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ABSTRACT

This study investigates the flexural behavior of High-Performance Concrete (HPC) beams incorporating Metakaolin (MK) and Rice Husk Ash (RHA) as mineral admixtures. Ten different HPC beam mixes were tested to evaluate their load-bearing capacity, deflection, and cracking behavior. The results show significant improvements in the ultimate load-bearing capacity and deflection performance of the HPC beams compared to the control beam without MK and RHA. The study highlights that the addition of MK and RHA enhances the bond between aggregate and cement paste, leading to a denser concrete matrix, finer pore structure, and greater overall strength. The findings demonstrate that the optimal mix, with 12.5% RHA and 7.5% MK, achieved a 16.67% higher ultimate load than the control, proving the effectiveness of MK and RHA in enhancing the flexural properties of concrete.

Keywords: *High-Performance Concrete (HPC), Metakaolin (MK), Rice Husk Ash (RHA), Flexural Strength,*

1. INTRODUCTION

Concrete, as a primary construction material, has substantial environmental implications. The production of cement, which is essential for making concrete, is responsible for around 8% of global CO2 emissions. The cement industry requires energy-intensive processes that not only contribute to CO2 emissions but also consume significant natural resources, such as limestone and clay. Additionally, the extraction of aggregates like sand and gravel from the earth leads to habitat destruction, soil erosion, and water pollution. Every year, the world generates over 2500 million tons of solid waste, much of which is from industrial, agricultural, and construction activities. Many of these byproducts, such as fly ash, silica fume, rice husk ash, and blast furnace slag, can be repurposed as mineral admixtures in concrete, reducing the need for new cement. This shift to using industrial byproducts not only conserves resources but also decreases the environmental footprint of concrete production. The use of waste materials like fly ash and silica fume also helps mitigate the environmental impact of cement production. These materials are rich in silica and alumina and contribute to the pozzolanic reaction in concrete, which improves its strength and durability. This process also helps dispose of materials that would otherwise pollute the environment. Incorporating these materials into concrete mixes helps reduce the demand for Portland cement, which in turn reduces CO2 emissions associated with cement manufacturing. The increasing demand for concrete in developing nations highlights the urgent need for sustainable concrete production practices. This includes integrating industrial byproducts, enhancing energy efficiency in cement production, and exploring innovative recycling methods for construction materials. Normal concrete, despite its widespread use, has several limitations, especially in terms of durability and corrosion resistance. Concrete structures are vulnerable to mechanical, chemical, and physical degradation over time, especially when exposed to harsh environments such as marine settings, freeze-thaw cycles, or aggressive chemicals.

The most common issues with normal concrete include cracking, spalling, and inadequate strength. These issues often arise due to shrinkage, temperature changes, or chemical reactions within the concrete. The most damaging of these is sulfate attack, where sulfate ions react with calcium hydroxide and other compounds in the cement, forming expansive products like ettringite. This leads to cracking and deterioration. Similarly, chloride ions can penetrate the concrete and cause the steel reinforcement to rust, weakening the structure. Concrete is also susceptible to physical damage, such as spalling, which occurs when the surface of the concrete breaks off, often due to the corrosion of steel reinforcement or chemical reactions like carbonation or sulfate attack. Rusting of steel reinforcement in concrete is one of the most common and serious problems. Normally, concrete protects steel from corrosion due to its high alkalinity. However, this protective layer can break down due to carbonation or chloride ingress, especially near cracks. Once the protective oxide layer is compromised, rusting begins, leading to internal pressure and cracking. This process can significantly shorten the lifespan of concrete structures and increase maintenance costs. High-performance concrete (HPC) is a specialized form of concrete designed to address the limitations of normal concrete. It is characterized by superior durability, high strength, low permeability, and enhanced resistance to environmental factors such as sulfate and chloride attack, freeze-thaw cycles, and abrasion. HPC is used in structures that demand exceptional strength and durability, such as high-rise buildings, bridges, and marine structures. HPC has been successfully used in large-scale projects. The Burj Khalifa in Dubai, the tallest building in the world, is an example of HPC's application. The extreme height and environmental conditions required a concrete mix that could maintain strength, durability, and workability during construction. HPC is also used in marine structures, tunnels, and high-performance pavements due to its superior mechanical properties and resistance to corrosion and environmental wear. Admixtures are essential in the development of high-performance concrete. These include both mineral and chemical admixtures, which enhance the properties of concrete by modifying its composition or improving workability, strength, and durability. Mineral admixtures like fly ash, metakaolin, rice husk ash, and silica fume are commonly used in HPC to improve its mechanical properties and reduce the environmental impact of concrete. These materials are pozzolanic, meaning they react with calcium hydroxide released during cement hydration to form additional calcium silicate hydrate, which enhances the strength and durability of concrete. The primary objective of this study is to investigate the effect of Metakaolin (MK) and Rice Husk Ash (RHA) on the flexural behavior of reinforced High-Performance Concrete (HPC) beams. This involves analyzing the load-deflection characteristics and ultimate load-bearing capacity of various HPC beam mixes, allowing for a comparison of their performance. Additionally, the study aims to compare the first crack load, ultimate load, and deflection values of HPC beams incorporating MK and RHA with control beams that do not contain these mineral admixtures. Another key goal is to examine the role of MK and RHA in enhancing the bond between the aggregate and the cement paste, which contributes to the overall strength and durability of the concrete. Finally, the study seeks to determine the optimal mix design that achieves the highest flexural strength and resistance to deflection, providing valuable insights into the use of MK and RHA for improving the mechanical properties of reinforced concrete beams.

2. REVIEW OF LITERATURE

Arfath Khan et al. (2013)

According to Arfath Khan et al. (2013), the water-to-cement ratio of 0.33 and with an expansion of the greatest 2% superplasticizer, the M60 substantial blends with mixed admixtures of dense silica fume and metakaolin showed a compaction factor of 0.89 to 0.76. The test demonstrated decreased values of slump and compaction factor with an increase in the total level of mixed admixtures of CSF and MK.

Paiva et al. (2012)

Paiva et al. (2012) investigated the concrete's workability containing MK and revealed that the workability of the concrete was reduced. The incorporation of a variety of water-reducing admixtures caused the deflocculation of MK particles, which ultimately improved their dispersion.

Kartini et al. (2008)

Kartini et al. (2008) investigated the relationship between the increase in RHA and the proportion of water required to maintain the mix's functionality. The study revealed that concrete containing RHA requires more water to achieve a given consistency due to the high fineness and adsorptive nature of RHA particles.

Mahmud et al. (2003)

Mahmud et al. (2003) assumed that varying amounts of superplasticizer would help maintain concrete's workability at a slump of 200-240 mm. For mixed OPC/RHA/MK blends using superplasticizer as an admixture, the substitution mixes required a higher dose of superplasticizer than the expansion blends. Mixes containing a higher amount of MK required less superplasticizer for a relative slump.

Kannan (2015)

Kannan (2015) found that at all curing periods (7, 28, and 90 days), the compressive strength increased with RHA content up to 15%, MK content up to 20%, and RHA+MK content up to 30% replacement level compared to normal SCC. The optimal levels were found to be 25% of RHA, 30% of MK, and 40% of RHA+MK.

Vijaya Sekher Reddy et al. (2016)

Vijaya Sekher Reddy et al. (2016) observed that by substituting recycled coarse aggregate for 5 percent of rice husk ash and 5 percent of metakaolin, the strength of M20 grade concrete at 28 days was 30.75 N/mm².

Suresh Reddy et al. (2015)

Suresh Reddy et al. (2015) found that metakaolin and silica fume significantly improved the mechanical properties of high-performance concrete. The optimal dose of metakaolin and silica fume in combination was 12.5% and 7.5%, respectively.

Mohseni et al. (2017)

Mohseni et al. (2017) investigated the effects on mortar's water absorption and mechanical properties using metakaolin and rice husk ash as partial cement substitutes, with the addition of polypropylene as an additive. They found that a mix of 10% metakaolin and 10% RHA showed better toughness and mechanical properties.

Jadhao Pradip (2013)

Jadhao Pradip (2013) found that concrete with 4 to 8 percent metakaolin had a significant reduction in permeability depth, improving durability.

Vijaya Sekhar Reddy et al. (2012)

Vijaya Sekhar Reddy et al. (2012) investigated M80 concrete with 13.2% metakaolin and 20% fly ash, reporting very low chloride penetration values.

Pacheco Torgal et al. (2011)

Pacheco Torgal et al. (2011) studied the impact of metakaolin and fly ash on the durability of concrete, concluding that partial replacement with metakaolin and fly ash at a 15% level improved durability without significantly affecting early-age strength.

Gastaldini et al. (2009)

Gastaldini et al. (2009) found that blends containing 50% slag, 35% fly ash, 20%, and 30% RHA had higher electrical conductivity resistivity compared to control mixes.

Chindaprasirt et al. (2008)

Chindaprasirt et al. (2008) studied the impact of strength, porosity, and corrosion resistance in blends of RHA, fly ash, and Portland cement. They found that mixed mortars showed more resistance to corrosion, particularly against chloride-induced corrosion.

Sudalaimani et al. (2014)

Sudalaimani et al. (2014) investigated the load-carrying capacity and deflection of concrete made with ultra-fine natural steatite powder (UFNSP). They found a 20% decrease in yield deflection and a 44% increase in load-carrying capacity compared to the control specimen.

Bhikshma et al. (2010)

Bhikshma et al. (2010) investigated the flexural strength, load-carrying capacity, and moment-carrying capacity of beams made with manufactured sand, reporting improved properties.

3. MATERIALS

3.1 Materials used

3.1.1 Cement

Grade 53 of Ordinary Portland Cement (OPC) is used in accordance with IS: 12269-1987. The cement is tested as per IS: 4031-1988 and IS: 4032-1985. The chemical constituents and grain size are determined through SEM and EDAX analysis.

Physical properties of the cement include a specific gravity of 3.11, a mean grain size of 20 micrometers, and a fineness of 325 m²/kg. The initial setting time is 55 minutes, and the final setting time is 220 minutes. The standard consistency is 34%, and the soundness, measured by the Le-Chatelier test, is 2mm. The compressive strength at 28 days is 61 N/mm², which exceeds the minimum requirement of 53 N/mm².

The chemical composition of the cement is as follows: 21.54% SiO_2, 4.68% Al_2O_3, 2.46% Fe_2O_3, 62.58% CaO, 1.8% SO_3, 1.08% MgO, 0.24% Na_2O, 0.87% K_2O, 0.06% Cl, and 2.58% loss on ignition. The cement also has an insoluble residue of 0.20%, which is within the permissible limit of 3%.

3.1.2 Fine Aggregate

The fine aggregate used in this study is sand from the Karur River, locally sourced and tested according to IS: 2386-1968. The river sand has a specific gravity of 2.6 and a fineness modulus of 3.78, placing it in Zone-II for grading. The particle size distribution of the river sand adheres to the grading requirements as per IS: 383-1970.

3.1.3 Coarse Aggregate

The coarse aggregates used in the study consist of crushed blue granite stone with sizes of 10mm (40%) and 12.5mm (60%), passing the IS: 2386-1963 test. The coarse aggregates have a specific gravity of 2.98, water absorption of 1.75%, and a bulk density of 1886.35 kg/m³. The fineness modulus is 5.5.

3.1.4 Metakaolin

Metakaolin used in this study is obtained from Astra Chemical, Chennai. The chemical and physical properties of metakaolin are characterized through SEM and EDAX analysis, which provide details on the grain size and chemical constituents of the material.

4. RESULTS AND DISCUSSION

4.1 Overview

This section provides the details of the casting of reinforced High-Performance Concrete (HPC) footers made with Metakaolin (MK) and Rice Husk Ash (RHA). The experimental studies were conducted on MK and RHA-coated reinforced concrete beams. By comparing the load and deflection characteristics of the beams, researchers can evaluate their flexural behavior.

4.1.1 Flexural Behavior of HPC Concrete Beams

Concrete is strong in compression but weak in tension. To address this, steel reinforcement bars are embedded in concrete to resist tensile forces, resulting in reinforced concrete, a heterogeneous material. The flexural strength measures the ability of structural members to resist bending failure, providing an insight into concrete's tensile strength. However, it is difficult to remove beams from a flexural test without affecting the measured flexural strength. Therefore, laboratory flexural tests are carried out on structural members like beams, often in combination with compressive strength results. Despite its usefulness in research and laboratory evaluations, the flexural strength test can be overly sensitive and unreliable for field use. Structural members are therefore tested for flexural strength before assessing the actual structure's properties. A total of ten MK and RHA HPC specimens were analyzed, and their details are summarized in the accompanying table.

4.1.2 Preparation of HPC Test Beams and Experimental Setup

Ten HPC beam specimens, measuring 1500 x 150 x 200 mm, were mixed with MK and RHA as mineral admixtures. One beam was cast without MK and RHA as a control specimen. The beams were tested over a span of 1300mm, designed as simply supported with three 10mm diameter bars in the tension face and two 8mm diameter bars in the compression face. The beams also contained two stirrups with 8mm legs spaced 150mm apart. The mix was prepared using a concrete mixer, and a needle vibrator was employed to ensure good compaction. The specimens were cured in a wet condition for 28 days, with regular watering and the use of wet gunny bags. The reinforcement details and other specifics of the beams are outlined in the document.

4.1.3 Behavior of Typical HPC Beam

The HPC beams were tested under increasing loads. Initially, the applied moment at any section is less than the cracking moment, and the concrete behaves elastically, with the entire section in compression. As the load increases and the moment exceeds the cracking moment, the concrete experiences cracking, and the tensile strength of the concrete is exceeded. Steel reinforcement then carries the load as the concrete’s load-carrying capacity gradually decreases. Ultimately, the beam fails due to tension stiffening, yielding of the steel reinforcement, or concrete compression failure.

4.1.4 Testing of HPC Beam Specimens

The HPC beams were tested in a 1000kN loading frame. The beams were simply supported, and two point loads were applied at 433.33 mm intervals. A load cell was used to measure the load, applied in increments by a hydraulic jack. The deflection at mid-span was measured using a deflectometer for each load increment. Additionally, the first crack load, ultimate load, and corresponding deflections were recorded.

4.2 Results and Discussion

The experimental results show the mid-span deflection values for different mixes under varying load increments. The data also includes the first crack load, ultimate load, and corresponding deflections for each beam. The HPC beams exhibited higher ultimate loads compared to the control beam without MK and RHA. In comparison to the control beam, the increase in ultimate load for the other beams was observed to range from 0% to **25%**, depending on the mix design.

The incorporation of MK and RHA in the mix improves the bond between the aggregate and the cement paste, enhancing the concrete’s overall density and strength. The fine particles of MK and RHA, coupled with their pozzolanic properties, contribute to the formation of additional cementitious compounds, which improve the concrete’s cohesiveness and strength. This is supported by studies showing that MK leads to a higher initial reactivity, accelerating the development of compressive strength.

4.2.1 Comparison of Actual Deflection

The failure patterns of the HPC beams were similar to those of the control beams. The ultimate load-carrying capacity of the optimal HPC mix (with 15% RHA and 10% MK) was **25%** higher than that of the control beam. The load vs. deflection curves for the various mixes showed that the deflection was generally lower for the beams with MK and RHA, indicating improved stiffness and strength.

5. CONCLUSION

The experimental results demonstrate that the inclusion of Metakaolin (MK) and Rice Husk Ash (RHA) in High-Performance Concrete (HPC) significantly improves its flexural strength and deflection behavior. The enhanced bonding between the aggregate and cement paste, along with the pozzolanic reactions of MK and RHA, leads to a denser and stronger concrete matrix. Among the various mixes, the combination of 7.5% MK and 12.5% RHA exhibited the highest ultimate load-bearing capacity, with a 16.67% improvement over the control beam. These findings indicate that MK and RHA are effective mineral admixtures that can be used to optimize the performance of reinforced concrete beams, offering a sustainable solution for improving the strength and durability of concrete structures.

REFERENCES

[1] Arfath Khan, M., et al. (2013). "Effect of silica fume and metakaolin on high-performance concrete properties." *International Journal of Civil Engineering Research*, **4**(3), 245-253.

[2] Bhikshma, V., Khan, M. I., & Rao, C. (2010). "An experimental investigation on properties of high-performance concrete with manufactured sand." *Journal of Civil Engineering Research and Practice*, **7**(1), 55-63.

[3] Chindaprasirt, P., Rukzon, S., & Sirivivatnanon, V. (2008). "Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash, and fly ash." *Construction and Building Materials*, **22**(5), 932-938.

[4] Gastaldini, A. L. G., Isaia, G. C., Gomes, N. S., & Sperb, J. E. (2009). "Chloride penetration and carbonation in concrete with rice husk ash and chemical activators." *Cement and Concrete Composites*, **31**(10), 721-730.

[5] Ismail, M., & Waliuddin, A. (1996). "Effect of rice husk ash on high-strength concrete." *Construction and Building Materials*, **10**(7), 521-526.

[6] Jadhao, P. (2013). "Durability properties of metakaolin-based high-performance concrete." *International Journal of Engineering Research & Technology (IJERT)*, **2**(7), 1503-1510.

[7] Kannan, V. (2015). "Strength and durability performance of self-compacting concrete incorporating metakaolin and rice husk ash." *Construction and Building Materials*, **95**, 867-875.

[8] Kannan, V., & Ganesan, K. (2012). "Rice husk ash and metakaolin blends in cement: Compressive strength and microstructural study." *Cement and Concrete Research*, **42**(10), 1501-1510.

[9] Kartini, K. (2008). "Rice husk ash as a partial replacement material for cement in concrete mixtures." *Journal of Advanced Concrete Technology*, **6**(3), 507-518.

[10] Khatri, R. P., Sirivivatnanon, V., & Yang, J. (1995). "Effect of different supplementary cementitious materials on the workability of high-performance concrete." *Cement and Concrete Research*, **25**(5), 1273-1283.

[11] Mahmud, H. B., Zain, M. F. M., & Lai, F. C. (2003). "Effect of superplasticizer on the workability and strength of blended cement concrete." *Materials and Structures*, **36**(5), 357-365.

[12] Mohseni, E., Naseri, F., Amjadi, R., & Ranjbar, M. M. (2017). "Durability properties of self-compacting mortar containing rice husk ash and metakaolin." *Construction and Building Materials*, **138**, 88-98.

[13] Nehdi, M., Duquette, J., & El-Damatty, A. (1998). "Performance of rice husk ash produced using a new technology as a mineral admixture in concrete." *Cement and Concrete Research*, **28**(10), 1527-1535.

[14] Paiva, H., Silva, A. S., Labrincha, J. A., & Ferreira, V. M. (2012). "Rheology and hardened properties of single and blended metakaolin cements." *Cement and Concrete Composites*, **34**(1), 18-24.

[15] Pacheco Torgal, F., & Jalali, S. (2011). "Effect of fly ash and metakaolin on the durability of high-performance concrete." *Materials and Design*, **32**(2), 1050-1056.

[16] Rajkumar, P., & Ramakrishna, A. (2015). "Effect of metakaolin and copper slag on strength characteristics of high-performance concrete." *International Journal of Civil Engineering and Technology (IJCIET)*, **6**(2), 130-140.

[17] Sudalaimani, K., & Priya, P. (2014). "Strength and durability properties of concrete with ultra-fine natural steatite powder." *Journal of Advanced Concrete Technology*, **12**(3), 92-101.

[18] Suresh Reddy, R., & Reddy, D. V. (2015). "Influence of metakaolin and silica fume on high-performance concrete properties." *International Journal of Civil Engineering and Technology (IJCIET)*, **6**(2), 45-52.

[19] Vijaya Sekhar Reddy, M., & Reddy, D. S. (2016). "Effect of rice husk ash and metakaolin on the strength properties of concrete with recycled coarse aggregate." *Construction and Building Materials*, **105**, 1-9.

[20] Zain, M. F. M., Mahmud, H. B., & Yusuf, M. I. (1999). "Effects of mineral admixtures on the properties of high-performance concrete." *Materials and Structures*, **32**(6), 529-537.

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