Journal of Civil and Mechanical Engineering
Volume 01, Issue 01, July 2025
www.ijcme.com

Mechanical Characteristics of Metakaolin Used in Concrete to Replace Part of the Cement

B Niharika
Department of Civil Engineering, Gitam University, Chennai
Corresponding Author: bniharikagitamce@gmail.com

To Cite this Article
Niharika, "Mechanical Characteristics of Metakaolin Used in Concrete to Replace Part of the Cement", Journal of Civil and Mechanical Engineering, Vol. 01, Issue 01, July 2025, pp:09-13.

***Abstract**: This study examines the mechanical characteristics of concrete whereby the part of the cements has been replaced by metakaolin. Various proportions of metakaolin, highly reactive pozzolanic material, formed by calcining kaolinite clay, were added by weight as: 5, 10 and 20% by weight of cement to concrete mixtures. The primary subjects of the study were the compressive, split tensile and flexural strengths in different ages of curing. Based on the findings, metakaolin enhances the microstructure and reduces the content of calcium hydroxide of concrete, which is stronger and durable, most particularly when replaced by 10 to 15% of metakaolin. To some extent, strength had a negative correlation with the level of replacement. With reduced amounts of cement and enhanced cement, it can be seen that metakaolin is helpful supplementary cementitious materials that lead to sustainable construction activities.*

***Keywords**: Compressive strength, Split tensile strength, Flexural strength, Metakaolin, Concrete mix*

I. Introduction

The search into the replacement of the ordinary Portland cement (OPC) with other materials to partially substitute its use to achieve sustainable and cost-effective solutions to the construction industry facilitated by the growing concern over the issue of sustainability and durability in the industry in the recent years. Manufacture of cement is very energy-intensive process that is a significant source of CO_2 emissions around the world. Supplementary cementitious materials like fly ash, silica fume and metakaolin are increasingly gaining popularity as a result of these difficulties. Of these, one of the most reactive pozzolanic materials is metakaolin which is derived through calcinations of kaolinite clay and exhibited very promising results in terms of durability and mechanical properties of concrete. Addition of metakaolin improves the microstructure of concrete due to the fact that it forms pozzolanic reactions through calcium hydroxide which form more calcium silicate hydrate (C-S-H) [1].

This boosts chemical attack resistance, reduces permeability and raises compressive strength. Metakaolin also makes concrete more long-lasting and high-performance besides reducing carbon emissions through the use of less cement. This research aims at investigating mechanical properties of concrete with metakaolin incorporated into it in various replacement levels (5%, 10%, 15% and 20 % by cement weight). In its bid to identify the optimal metakaolin dosage to enhance performance and sustainability of concrete construction, the project evaluates other significant properties, including the compressive strength, split tensile strength and flexural strength.

II. Literature Survey

Many studies have been conducted regarding the impact of metakaolin on the mechanical properties of concrete focusing on the effectiveness with which it can be used to partially replace cement. Metakaolin, one of the pozzolanic materials that consists of calcined kaolinite clay, enhances the microstructure of concrete by exerting hydration using calcium hydroxide and generating additional calcium silicate hydrate (C-S-H). The response brings about strength and durability. Sabir et al. (2001) found that addition of metakaolin of cement to the concrete matrix enhanced both compressive and precious strength of concrete. Justice and Kurtis (2007) show that metakaolin enhances durability due to its reduction capacity on porosity and strengthening of the substance at the early stages of its process. Badogiannis et al. (2004) also state that metakaolin reduces permeability and enhances resistance to sulphate attack [2-5].

Other researchers such as Siddique and Klauss (2009) have reported that extensive up to 20% replacement can be used to increase tensile strength and durability without compromising workability when appropriately mixed. But excess usage beyond the optimal range may cause reduced workability and excess water usage that led to reduced performance. All in all, studies indicate that metakaolin is an effective replacement of cement that improves durability and mechanical properties of concrete. Anywhere between 10 and 15% will be the ideal replacement level that will strike a balance between sustainability benefits and performance improvement.

III. Materials Used

One of the materials found in this study is Ordinary Portland Cement (OPC) 43 grade as the primary binder that will be used to investigate the mechanical properties of metakaolin based concrete [2-6]. Metakaolin a highly reactive pozzolanic material obtained by calcining pure kaolinite in-clay to 650-800^0 C was used to partially replace cement at 5, 10 to 20% by weight. The use of aggregates in this context followed the requirement of IS:383 stipulation (crushed stone that measures up to 20 mm and river sand). This was combined with and treated using drinkable water. Limited doses of a superplasticizer were used to maintain consistency and to improve workability. The physical properties of all materials were checked before being put into use to ensure they were within the Indian standards which applied.

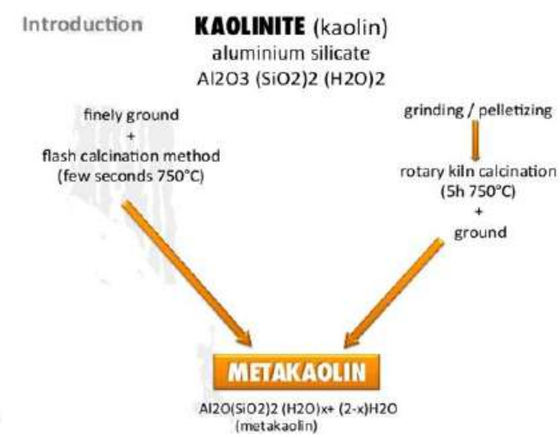

Fig 1: Matakaolin formulation

Fig 2: Matakaolin appearance

IV. Experimental Program

The objective of the experiment program was to determine the mechanical properties of concrete made with the use of metakaolin in lieu of a part of cement. Metakaolin replaced Ordinary Portland Cement (OPC) 43 grade at a weight percentage of 0 to 20%. The mix of concrete was prepared with a goal compressive strength of M30 and water-cementitious material ratio of constant 0.45. The compression, split tensile and flexural strength were determined using standardized cubes (150x 150x 150 mm), cylinders (150x 300 mm), and beams (100x 100x 500 mm). The specimens were cured in water; the specimens were cured after 7 days, 28 days and 56 days. IS:5816 was followed in carrying out the tests of split tensile strength whereas fiber strength was determined as per IS:516 in determining compressive resistance as well as flexural strength. Fresh concrete was tested to establish its workability in terms of the slump cone. The primary objective involved finding the optimum metakaolin content that could provide the optimum increase in strength without adversely affecting workability.

V. Results and Discussion

Metakaolin partial replacement of cement had a significant influence on the mechanical behavior of the concrete as revealed by the experimental results. Compressive strength increased around 15% compared to the control mix with a metakaolin content of up to 15%, at 28 days it was about 15%–20% higher than the control mix. The improvement is due to the formation of more calcium silicate hydrate (C-S-H) and being the interface densified through the pozzolanic reaction between the (Ca(OH) 2).nH $_2$ O and metakaolin. Trends were found to be similar in split tensile and flexural strengths and maximum values were obtained at the replacement levels of 10–15%. A small reduction in strength (above 15%) was observed at higher content, this was likely due to poor dispersion of metakaolin and from a loss of workable and micro-voids associated with increased water demand [5-6].

Fig 3: Testing compression

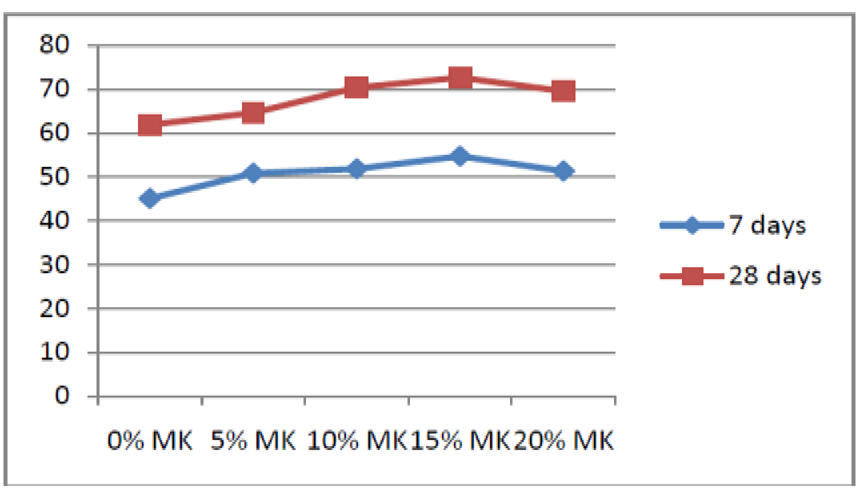

Fig 4: Compression strength

When the percentage of replacement with the metakaolin is over 10%, superplasticizer must be incorporated because the results for the slump test showed that the workability diminished as the content of metakaolin increased. At the optimum replacement (10–15%), metakaolin improved the bond between the paste and aggregates, and the overall mechanical properties. In summary, the strength and durability of concrete can greatly be enhanced by substituting up to 15% metakaolin for cement. There is a need to consider a mix design and use the additives, to counter the effect of reduced workability in the case of higher replacement level.

Fig 5: Testing of split tensile

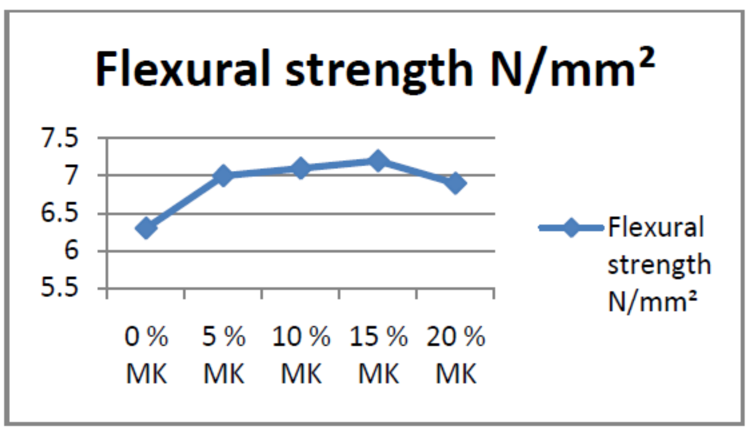

Fig 6: Flexural strength of compression

VI. Conclusion

Based on the results of this investigation, metakaolin is a beneficial admixture for enhancing mechanical properties of concrete. Metakaolin also exhibits a pozzolanic reaction which enhances the concrete matrix, and can replace up to 15% of the cement, increasing compressive, flexural, and tensile strengths. Nevertheless, due to inefficient dispersion and higher water requirement, replacement levels higher than 15% could likely lower strength and workability. Overall, metakaolin offers an environmentally friendly alternative to cement, and improves the strength and durability of concrete and reduces the adverse environmental impacts of this ubiquitous construction material. Optimum performance of design and admixture is obtained when design and admixture usage is properly performed.

References

[1] Mohan kumar, Vamsi Yadav, Sneha reddy and Jagan, "Study of charcteristics of cement in different applications", Springer lecture notes, Coimbatore, vol 5(1), pp 745-755, 2010.

[2] T Vijay muni, Srinivasa Varma and Srinath Reddy, "Implementation of neural technology for application of cement in various scenarios", IEEE Trans. Vol 8(1), pp 2134-2154, 2014, Chennai.

[3] Kumar naik, Narendra kumar, Yaaseen,"Properties of high performance concrete systems in corporating large amounts of high lime fly ash; Construction And Building Materials. Vol.4.No 1.Pp.231-242.

[4] M.B.Kumthekar, G.S.Vyas, N.T.Suryawanshi and M.B.More," Techno-Economical Benefit of Metakaolin Over Microsilica in Developing High Performance Concrete", CE&CR July 2010,pp. 954-966.

[5] Moksha naik, mohan and Tarak Rao," High reactivity metakaolin for high strength and high performance concrete", The Indian Concrete Journal, December 2008, pp.121-131

[6] SK Abdul Rehaman, John Vangli and Shanli, "Neural network system combined with Fuzzy-rough data reduction with ant colony optimization," *Fuzzy Set Syst*., vol. 231, pp. 56-65, March 2010.