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Performance Of Concrete Using Partial Replacement Of Cement By Metakaolin

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ABSTRACT:

Cement is one of the main sources causing environmental impacts through concrete usage. Recent advances in the construction sector have dramatically increased the usage of concrete. It has become the second-largest consumed material in the world next to water. As per IBEF (Indian Brand Equity Foundation) report 2021, the production of cement is estimated to grow by around 20 per cent and surpass pre-covid levels to reach around 355 million metric tonnes in the year 2022. In order to overcome the negative impact on the environment due to CO2 emissions during manufacturing of cement, the researchers are in search of alternative materials that can replace cement. This could be achieved by replacing a part of cement with mineral additions such as Metakaolin. Metakaolin is a material obtained by calcination of kaolinite mineral at 650 and 900 degrees. The proportional use of a combination of Metakaolin improves the properties and performance of concrete. Proper Metakaolin type Selection and dosage of the Metakaolin are the key factors that affect concrete performance. The main objective of the current study was to assess the suitability of Metakaolin as supplementary cementitious material and also its performance when used with steel slag in a ternary blend mix. Experimental investigations were carried out to study the effect of addition of Metakaolin as supplementary cementitious material on various parameters of concrete,

Keyword- Metakaolin, durability concrete, Steel Slag, Compressive Strength, supplementary cementitious material

1. 1 Introduction :

The most exceedingly used man-made building material in the world is concrete. Nowadays, concrete is being used on a large scale due to the rapid growth of the construction industry worldwide. Concrete is a predetermined proportion of cement, fine aggregate, coarse aggregate and water produced to achieve desired strength at the specific age. Concrete constituents are obtained from different sources, differing in their physical, chemical and reactive characteristics. This requires the study of concrete ingredient properties and concrete characteristics. Recent advances in the construction sector have dramatically increased the usage of concrete. It has become the second-largest consumed material in the world next to water. By using such a massive amount of concrete results in huge demand for cement and other raw materials. Due to this, the global demand of cement has reached about 5 to 7 billion metric tons every year [. In the production process of OPC natural resources (Limestone) are getting exhausted at a faster rate and greenhouse gases are released in to the atmosphere by consuming huge energy during calcination of cement. During the cement manufacturing process, about 7% to 8% of man-made CO2 emission is released into the atmosphere .

Metakaolin

Metakaolin can be used as an accelerator as well as fill up the interparticle spaces of cement grains as they react with Ca(OH)2, produced during cement hydration process, which further activates the process of mineralization, significantly enhance the mechanical and microstructural characteristics of concrete in comparison with ordinary Portland cement (OPC) alone, provided there is adequate curing

1. 2 Literature survey & background :

Jian-Tong Ding et al (2002) experimentally found out the effects of Metakaolin and Silica Fume on the properties of Concrete. Experimental investigation with seven concrete mixtures of 0, 5, 10, and 15% by mass replacement of cement with high-reactivity Metakaolin or Silica fume, at a water cement ratio of 0.35 and a sand-to-aggregate ratio of 40% was carried out. The effect of Metakaolin or Silica fume on the workability, strength, shrinkage, and resistance to chloride penetration of concrete was investigated. The incorporation of both Metakaolin and Silica fume in concrete was found to reduce the free drying shrinkage and restrained shrinkage cracking width. It is also reported that the incorporation of Metakaolin or Silica fume in concrete can reduce the chloride diffusion rate significantly. The performance of Silica fume was found to be better than Metakaolin

Badogiannis.E et al (2004) evaluated the effect of Metakaolin on concrete. Eight mix proportions were used to produce high-performance concrete, where Metakaolin replaced either cement or sand of 10% or 20% by weight of the control cement content. The strength development of Metakaolin concrete was evaluated using the efficiency factor (k value). With regard to strength development the poor Greek Metakaolin and commercially obtained Metakaolin yielded the same results. The replacement with cement gave better results than that of sand. When Metakaolin replaced cement, its positive effect on concrete strength generally started after 2 days where as in case of sand it started only after 90 days. Both Metakaolin exhibited very high k-values (close to 3.0 at 28 days) and are characterized as highly reactive pozzolanic materials that can lead to concrete production with excellent performance.

Nabil M. Al-Akhras (2005) carried out an investigation by replacing cement with Metakaolin to find out the durability of concrete against sulphate attack. Three replacements of cement with Metakaolin (5, 10 and 15% by weight) were done with water cement ratio of 0.5 and 0.6. After the specified days, the samples were immersed in 5% sodium sulphate solution for 18 months. The effect of metakaolin addition proved to be beneficial in improving the resistance of concrete to sulphate attack. Metakaolin with water cement ratio of 0.5 exhibited better results in sulphate resistance than 0.6. Autoclaved cured specimens had better resistance against sulphate than moist cured specimens.

Abid Nadeem et al (2008) made an investigation on the chloride permeability of high strength concrete and mortar specimens containing varying proportions of Metakaolin (MK) and Fly ash at elevated temperatures. A total of seven concrete and three mortar mixes were tested after exposing each mix to 200, 400, 600 and 800°C. In concrete, the dosage levels of MK were 5, 10 and 20% and for Fly ash the dosage levels were 20, 40 and 60%. In mortar, the dosage level of Metakaolin and Fly ash was 20%. All concrete specimens investigated in this study had a minimum compressive strength of 85 MPa.

Jiping Bai and Albinas Gailius (2009) developed statistical models for predicting the consistency of concrete incorporating Portland cement, Fly ash and Metakaolin from the experimental results of standard consistency tests. The effect of variations of pozzolanic replacement materials including Fly ash and Metakaolin replacement levels up to 40% and 50% respectively were tried. Consistency parameters were found out from the best fit models.

Pacheco Torgal.F et al (2011) determined the effect of Metakaolin and Fly ash on strength and durability of concrete. The durability was found by three methods namely water absorption, oxygen permeability and concrete resistivity. They reported that partial replacement of Portal and cement by 30% fly ash leads to serious decrease in early age compressive strength than the reference mix made with 100% Portland cement. The use of hybrid of them at 15% Fly ash and 15% Metakaolin based mixtures resulted in minor strength loss at early stages but showed outstanding improvement in durability.

Murali.G and Sruthee P(2012) experimentally studied the use of Metakaolin as a partial replacement substance for cement in concrete. The use of Metakaolin in concrete effectively enhanced the strength properties. The optimum level of replacement was reported as 7.5%. The result showed that 7.5% of Metakaolin increased the compressive strength of concrete by 14.2%, the split tensile strength by 7.9% and flexural strength by 9.3%

Vikas Srivastava et al (2012) investigated the suitability of silica fume and metakaolin combination in production of concrete. The optimum combined doses of silica fume and Metakaolin were found out as 6% and 15% (by weight) respectively. The specimens where cast and tested on 7th, 14 th and 28 days. The 28th day compressive strength of concrete generally increased with the Metakaolin content for at all the Silica fume contents. The 7th day compressive strength of concrete was found to decrease with the increase in Metakaolin content for all the Silica fume contents.

Dojkov.I et al (2013) experimentally studied the reaction between Metakaolin-Ca(OH)
2 -water and Fly ash- Ca(OH) 2 -water. It was clear that during the initial period of curing (up to 7 days), Metakaolin combined lime with a very high rate. This indicated that the overall rate of the reaction taking place in early age of Portland cement - Metakaolin concretes and cement mortars was limited by the hydration of the cement phases. The reaction between Fly ash- Ca(OH) 2 -water was taking place at a moderate rate in the initial age as compared with Metakaolin-Ca(OH)
2 -water.

Arka Saha et al. (2014) conducted a study on "Strength development characteristics of high strength concrete incorporating an Indian fly ash". The study generally focuses on the feasibility of using fly ash as a replacement material in the concrete production. In this paper the cement is replaced by fly ash and it ranges between 0 - 40 %. The investigation was done in such a way that the water cement ratio lies between 0.27 to 0.42 and the cement content varies from 430 to 550 kg/m3 . Compressive strength of the concrete was determined for 7, 28 and 90 days curing. From the studies they reached to the conclusion that increase of the fly ash upto a certain limit decreases the strength of the concrete and the optimum percentage found was 10.

Syed Afzal Basha [16] et al. (2014) in his paper "Compressive strength of fly ash based cement concrete", fly ash is being replaced with cement for the experimental studies. M25 and M30 grade concrete was used as the design mix for the investigation. The compressive strength of the concrete for 7, 14, 21 and 28 days curing were done. The fly ash replacement with cement ranges between 0% to 40% with an increment of 10%. The comparison is done with control mix. From the paper it concludes that the increase of fly ash decreases the strength of the concrete

Barbhuiya S et al. (2015) in the paper "Microstructure, hydration and nanomechanical properties of concrete containing metakaolin" presents the results of an experimental investigation carried out to evaluate the properties of concrete containing metakaolin. The properties of concrete containing metakaolin at 0%, 5%, 10% and 15% by mass of cement were studied for their compressive strength, sorptivity and carbonation resistance at two different water–binder ratios. It was found that 10% of the Portland cement could be beneficially replaced with the metakaolin to improve the sorptivity and carbonation resistance of concrete. To better understanding the properties various analytical techniques such as XRD, MIP and nanoindentation studies were carried on cement paste samples (with and without 10% MK). Test results showed that the incorporation of metakaolin modifies the cement paste in four different ways. Firstly, by transforming portlandite into C–S–H gel by means of pozzolanic reaction, secondly by reducing the porosity, thirdly by creating nucleation sites for hydration and finally, by modifying the relative proportions various phases of C–S–H gel.

Bhaskara Teja Chavali et al. (2016) in his paper "Effect of varying quantities of Metakaolin and fly ash on strength characteristics of concrete" studies the effect of adding Metakaolin along with fly ash in the concrete on its performance. The replacement was done in a pattern of 0% of Metakaolin and fly ash replacement, 15% of Metakaolin to cement and 30% of fly ash to cement separately and afterwards the combined effect of 15% Metakaolin and 30% of fly ash to cement were calculated. Concrete mix of M40 grade was used for the experimental investigation. The cubes, cylinders and prisms were tested for compressive strength, split tensile strength and flexural strength respectively. The tests are performed after 7 days and 28 days curing of the specimens. The experimental study shows that 15% of Metakaolin to cement gives more strength than the combined percentage of the cementitious materials. The replacement of fly ash of 30% and the combined percentage of 15% of Metakaolin and 30% of fly ash gives strength slightly less than that of the control specimen.

Teja Kiran Ch et al. (2016) in his paper "Strengthening of concrete by partial replacement of cement with fly ash and Metakaolin mix" deals with the effect of mineral admixtures incorporated with cement replacement and keeping the water cement ratio same for the ordinary concrete and modified concrete. 0, 5, 10, 15, 20, 30 percentages of fly ash and Metakaolin was partially replaced to cement and the best proportion that give the maximum strength was obtained. Concrete mix of M20 grade was used for the experimental investigation. The compressive strength and the flexural strength of the concrete were tested. Optimum percentage of Metakaolin alone and fly ash alone was determined and the optimum percentages of the two materials were combined to find the best proportion in case of compressive as well as flexural strength. The specimens, cubes and beams were tested after 7 days and 28 days of curing. The comparison of the results between the control specimen and the modified concrete were done.

Usha K et al. (2023) conducted a study on "Suitability of Fly Ash in Replacement of Cement in Pervious Concrete". The study investigates the effects on the important engineering properties of pervious concrete with the use of fly ash The physical properties examined include compressive strength, flexural strength, split tensile strength and permeability of pervious concrete. The cement was replaced by 0, 10, 20 and 30 percentages fly ash. Concrete mix of M15 grade pervious concrete was used for the experimental study with varying percentages of cementitious materials. Water and super plasticizer in liters are used in the mix. Based on the results of trial mix the proportions which is resulted in higher compressive strength value with good workability is selected for the final mix, to find 28th day compressive strength and other strength properties. The specimens, cubes and cylinders were tested for compressive strength and split tensile strength with 7 days and 28 days of curing. From the results of considered parameters, it is observed that 20% replacement of cement with fly ash showed better performance compared to pervious concrete without fly ash.

Findings of Literature Review

This chapter summarizes the extensive literature survey regarding fresh properties, mechanical properties, and durability properties of concrete containing Metakaolin or steel slag as partial substitute to cement. The utilization of Metakaolin as substitute material to cement decreases the workability of concrete; amplifies the strength and durability of concrete. The addition of steel slag as partial substitute to cement increases the workability of concrete also slightly enhances the strength and durability of concrete. These properties are depending upon the source and size of the material. Very few literatures are available on the optimum dosage of Metakaolin and utilization of Metakaolin in ternary blended concrete along with steel slag. Also, the effect of accelerated curing on performance of concrete containing Metakaolin as substitute to cement needs to be studied.

Literature shows that Metakaolin can be considered as pozzolanic material for partial substitute of cement. • High reactive Metakaolin shows high pozzolanic reactivity and reduction in calcium hydroxide even as early as one day. The cement paste undergoes distinct densification which increases the strength and decreases the permeability. • The high reactive Metakaolin is having the potential to compete with silica fume. It has noticeable effect on compressive strength of concrete. • The flexural strength considerably starts to increase upon its addition. Reduced effects of ASR. Increased durability and reduced potential for efflorescence.

In India MK can be produced in large quantities, as it is a processed product of kaolin mineral which has wide spread proven reserves available in the country. • At present the market price of MK in the country is about 2–3 times that of cement. Therefore, the use of Metakaolin proves economical over that of silica fume. • A lot of interest in MK is developing as it has been found to possess both pozzolanic and micro-filler characteristics.

EXISTING RESEARCH GAP

The following gaps were observed after the literature survey: • Due to the relatively recent popularization of studies in this sector, there is a scarcity of quantitative data on durability of Metakaolin concrete, ternary blend concrete using Metakaolin and Steel Slag and also high strength Metakaolin concrete with locally available sand and aggregates. • There have been less studies on durability and strength properties of Metakaolin based concrete under accelerated curing conditions.

1.3 Conclusion :

Metakaolin is a valuable supplementary cementitious material that enhances concrete's performance in terms of strength, durability, and sustainability. Proper dosage and mix design are crucial to maximizing its benefits, making it a preferred choice for demanding applications like marine structures, bridges, and high-rise buildings.

Enhanced Strength

1. Metakaolin contributes to increased compressive, tensile, and flexural strength due to its pozzolanic reaction with calcium hydroxide, forming additional calcium silicate hydrate (C-S-H).
2. Optimal replacement levels, typically between 5-15% of cement by weight, yield the best results

Durability Improvements

- **Reduced Permeability**: It decreases the porosity of concrete, enhancing resistance to water ingress and chloride penetration.
- **Chemical Resistance**: Improves resistance against sulfate attacks, alkali-silica reaction (ASR), and carbonation.
- **Reduced Efflorescence**: Mitigates the leaching of calcium hydroxide, minimizing white deposits on surfaces.

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