A LITERATURE REVIEW ON THE EFFECT OF METAKAOLIN AND FLY ASH ON STRENGTH CHARACTERISTICS OF CONCRETE

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ABSTRACT

The overall production of the cement has greatly increased which results lots of problems in environment as it involves the emission of CO_2 gas. Environmental concerns, stemming from the high energy expense and carbon dioxide emission associated with cement manufacture have brought about pressures to reduce cement consumption through the use of supplementary materials. Materials such as Metakaolin, fly ash have good pozzolanic activity and are a good material for the production of high strength concrete which is getting popularity because of its positive effect on various properties of concrete. In this review the mechanical properties of Metakaolin and fly ash as a supplementary cementitious material are discussed.

Keyword: - *Metakaolin, fly ash, supplementary cementitious material*

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1. INTRODUCTION

Concrete means a mixture of a binding material, aggregates as filler materials and water. The cement concrete is a mixture of cement, sand, pebbles or crushed rocks and water. The cement concrete has attained the status of a major building material in the modern construction. Although Portland cement demands are decreasing in industrial nations, it is increasing dramatically in developing countries. Cement demand projections shows that by the year 2050 it will reach 6000 million tons. Portland cement production leads to major CO_2 emissions accounting for almost 0.7 tons of CO_2 per ton of cement, which represents almost 7% of the total CO_2 world emissions. Not only CO_2 releases from cement manufacture but also SO_3 and NO_3 which can cause the greenhouse effect and acid rain. Since Portland cement is used mostly in concrete production, the most important building material on Earth, partial replacement by pozzolanic by-products and mineral additions will allow relevant carbon dioxide emission reductions.

Supplementary cementitious materials (SCM) are finely ground solid materials that are used to replace a portion of the cement in a concrete mixture. The supplementary cementitious materials may be naturally occurring or man-made waste. Various types of pozzolanic materials that improve cement properties have been used in cement industry for a long time such as Metakaolin and fly ash. Metakaolin possesses a high reactivity with calcium hydroxide having the ability to accelerate cement hydration. Since current concrete structures present higher permeability levels that allow aggressive elements to enter, leading corrosion problems, using pozzolanic admixtures not only reduce carbon dioxide emissions but also allow structures with longer service life, thus lowering their environmental impact. Fly Ash is one of the major waste materials available from thermal power plants and its treatment and disposal was a problem in the early stages. When fly ash is replaced with OPC, it reacts with the calcium to form the calcium silicate hydrate (C-S-H) gel. From previous works it is evident that they are very effective pozzolanic materials and effectively enhances the strength parameters of concrete.

2. LITERATURE REVIEW

Mermerdas K [6] et al. (2012) in the paper "Strength development of concretes incorporated with metakaolin and different types of calcinedkaolins" investigated the effects of metakaolin and calcinedkaolins on the concrete. For this, non purified ground kaolins obtained from different sources were thermally treated at specified conditions. Commercially available metakaolin from Czech Republic was used for comparison. Replacement levels (5%, 10%, 15%, and 20%) of calcinedkaolins and metakaolin were assigned for concrete production. One plain mix without admixture was produced as reference. Compressive strength development of the concretes was carried out at 3, 7, 28, and 90 days. The strength development of concretes was evaluated by statistical technique named GLM-ANOVA. From gene expression programming a prediction model was derived to evaluate the parameters affecting the strength. SiO_2, Al_2O_3, kaolinite, and alunite contents, fineness of mineral admixture, age of concrete, and replacement level were the parameters investigated. The experimental investigations showed that type of thermally treated kaolin, the replacement level, and age are very effective on the strength development of the concretes. The seven parameters in the prediction model was compared with the experimental results and proved to be a handful tool for estimating compressive strength of concrete incorporated with commercial metakaolin and calcinedkaolins

Ramezanianpour A.A[12] et al. (2012) in his paper "Influence of metakaolin as supplementary cementing material on strength and durability of concretes " investigates the performance of concrete mixtures containing local metakaolin in terms of compressive strength, water penetration, sorptivity, salt ponding, Rapid Chloride Permeability Test (RCPT) and electrical resistivity at 7, 28, 90 and 180 days. The microstructure of the cement pastes incorporating metakaolin was studied by XRD and SEM tests. The percentages of metakaolin that replace PC in this research are 0%, 10%, 12.5% and 15% by mass. The water/binder (w/b) ratios are 0.35, 0.4 and 0.5 having a constant total binder content of 400 kg/m3. Results show that concrete incorporating metakaolin had higher compressive strength and metakaolin enhanced the durability of concretes and reduced the chloride diffusion. There exhibit an exponential relationship between chloride permeability and compressive strength of concrete. A significant linear relationship was found between Rapid Chloride Permeability Test and salt ponding test results.

Nova John [9] (2013) in her paper "Strength Properties of Metakaolin Admixed Concrete" studies the effect of Metakaolin as mineral admixture in the concrete on its performance. The replacement was done in a pattern of 0, 5, 10, 15 and 20% to cement by Metakaolin. Concrete mix of M30 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 results indicate that the use of Metakaolin in concrete has improved the strength characteristics of concrete. From the results of considered parameters, it is observed that 15% replacement of cement with Metakaolin showed better performance in case of strength parameters such as compressive, flexural and split tensile strength.

Rashad A. M [13] et al. (2013) in his paper "Metakaolin as cementitious material: History, scours, production and composition –A comprehensive overview" deals with an overview of the previous works carried out on kaolin. Kaolin can satisfy the world demand for filler, paper and ceramic industries. Kaolin converts to a pozzolanic material named metakaolin after suitable thermal treatment. From the investigations it has proved that metakaolin can be used in mortar and concrete to enhance their properties. It can also be used as a source of cementing materials in alkali activation or geopolymer.

Siddamreddy Anil Kumar Reddy [14] et al. (2013) in his paper "Effect of Fly Ash on Strength and Durability Parameters of Concrete" studies the effect of adding fly ash in the concrete on its performance. The replacement was done in a pattern of 0, 5, 10, 15 and 20% to cement by fly ash. Concrete mix of M20 grade was used for the experimental investigation. The cubes and cylinders were tested for compressive strength, split tensile strength respectively. The tests are performed after 7 days and 28 days curing of the specimens. Durability studies were conducted on acid attack and percentage of weight loss is compared with control specimen. The results indicate that the use of fly ash in concrete has improved the strength characteristics of concrete as well as the durability behaviour. From the results of considered parameters, it is observed that 20% replacement of cement with fly ash showed better performance in case of strength parameters such as compressive and split tensile strength.

Arka Saha [1] 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/m^3. 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.

Guneyisi E [4] et al. (2014) in the paper “Combined effect of steel fiber and metakaolin incorporation on mechanical properties of concrete” reports the results of an experimental study on mechanical properties of plain and metakaolin (MK) concretes with and without steel fiber. To develop the metakaolin included steel fiber reinforced concrete mixtures, Portland cement was partially replaced with metakaolin as 10% by weight of the total binder content. Two types of hook ended steel fibers with length/aspect ratios of 60/80 and 30/40 were utilized to produce fiber reinforced concretes. Two series of concrete groups were designed with water to binder ratios (w/b) of 0.35 and 0.50. The effectiveness of MK and different types of steel reinforcement on the compressive, flexural, splitting, and bonding strength of the concretes were investigated. All tests were conducted at the end of 28 days of curing period. Analyses of variance on the experimental results were carried out and the levels of the significance of the variables on the mechanical characteristics of the concretes were determined. Moreover, correlation between the measured parameters was carried out to better understand the interaction between mechanical properties of the concretes. The results revealed that incorporation of MK and utilization of different types of steel fibers significantly affected the mechanical properties of the concretes, irrespective of w/b ratio.

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 [2] 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.

Mirmoghtadaei R [7] et al. (2015) in the paper “The impact of surface preparation on the bond strength of repaired concrete by metakaolin containing concrete” studies the influence of various types of surface preparation on bond strength of repaired concrete is evaluated. Six different surface textures are studied: as-cast; wire brushed; acid etched; grooved; grooved-wire brushed; grooved-acid etched. According to ASTM C882, 144 half-specimens as substrate concrete are cast. To form full-specimens, metakaolin containing repair concrete is poured on half-specimens. The bond strength of all specimens is measured through the slant shear method at the ages of 7, 28, and 90 days and compared with one another. According to the results, grooved-acid etched led to the highest bond strength in comparison to other types of surface preparation. For all surface preparation methods, replacement of metakaolin with 10% of cement instead of 0% or 15% in repair materials leads to have better bond strength

Subramani T [15] et al. (2015) conducted a study on “Experimental study on partial replacement of cement with fly ash and complete replacement of sand with M sand”. In this paper the effect of fly ash and M sand in the concrete is being studied. The cement is replaced by fly ash and the natural sand is replaced by M sand and the comparison is being investigated. Basic mechanical strength parameters such as compressive strength, split tensile strength and flexural strength is being determined for different curing periods of 7,14 and 28 days. The mix proportion used was of M25 grade. Natural sand was replaced completely and the fly ash was replaced of the range 25 to 35% with an increment of 5%.

Bhaskara Teja Chavali [3] 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.

Hossam S et al. [5] (2016) in the paper “Time-dependence of chloride diffusion for concrete containing metakaolin” investigated chloride diffusion and permeability in concrete containing metakaolin. Fifty-three concrete mixtures were tested based on a refined statistical analysis. Enhanced response surface method (RSM) was used to present the most significant factors affecting the chloride diffusion at different ages. The tested mixtures contained various water-to-binder (W/B) (ratios 0.3–0.5), metakaolin (MK) replacement (0–25%), and total binder content (350–600kg/m3). Bulk diffusion test was adopted for two years to determine the time-dependent coefficient m of chloride diffusion for all mixtures based on the error function solution to Fick's law. This coefficient was calculated based on two different bulk diffusion test methods: total and average methods. Design charts were developed to facilitate the optimization of mixture proportions for designers/engineers. The investigation also included some experimental relationships between the rapid chloride permeability test (RCPT), chloride diffusion coefficient, and compressive strength results. The results showed that the values of the chloride diffusion indicated a general reduction from 28 days to 760 days of testing. As the percentage of MK or binder content increased or as the W/B ratio decrease, the chloride diffusion reduction coefficients, m_{total} and m_{avr}, were found to increase. Based on the analysis of variance (ANOVA) from the statistical model, MK was found to be the most significant factor affecting the chloride diffusion at late ages (360 and 720 days), while the W/B ratio was the most significant factor affecting early ages of chloride diffusion(28 and 90 days). And the developed models and design charts in this paper are of special interest for aiding the prediction of service life of concrete containing MK.

Narmatha M [8] et al. (2016) conducted a study on “Meta kaolin –The Best Material for Replacement of Cement in Concrete”. The study investigates the effects on the important engineering properties of concrete with the use of Metakaolin. The physical properties examined include compressive strength, flexural strength and split tensile strength of the concrete. The cement was replaced by 0, 5, 10, 15 and 20 percentages of metakaolin. Concrete mix of M60 grade concrete was used for the experimental study with varying percentages of cementitious materials. 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 15% replacement of cement with metakaolin showed better performance compared to concrete without metakaolin.

Ogale R A [10] et al. (2016) conducted a study on “Effect of Metakaolin and fly ash on strength of concrete”. The paper investigates the effect of fly ash and Metakaolin by partially replacing cement. Metakaolin and fly ash are taken as the supplementary cementitious materials which show good pozzolanic activity and production of high strength concrete. The cement was replaced by 0, 5, 10, 15, and 20 percentages of Metakaolin and fly ash. Concrete mix of M20 grade was used for the experimental study with varying percentages of cementitious materials. The specimens, cubes and cylinders were tested for compressive strength and split tensile strength with 7 days and 28 days of curing. The experimental data shows that there was a reduction in the strength beyond 10% of the cementitious materials.

Pandhye R.D [11] et al. (2016) in his paper “Cement replacement by fly ash in concrete” the suitability of fly ash as a replacement to cement is being investigated. Mix proportions of grade M30, M40 and M50 were used for the study. The cement was replaced by the fly ash in varies percentages from 0% to 60%. The effect of adding fly ash in the concrete was investigated on the fresh concrete and the hardened concrete. Compressive strength of the concrete of 7 day, 28 day and 45 day curing were considered. Compaction factor test has been done so as to find the workability of the mix proportions. The comparison between the each mix has been done to analyse the suitability of fly ash in the concrete as a replacement material.

Teja Kiran Ch [17] 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 [18] et al. (2016) 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.

3. CONCLUSION

The use of Metakaolin and fly ash as a supplementary cementitious material is recommended because of its various benefits like increased service life, increased performance and improved appearance in a number of cement based systems. From the studies conducted, several percentages of replacement are done to investigate the mechanical properties of modified concrete with control mix. Alone the use of Metakaolin gives better strength as comparing it with the combined strength of fly ash and Metakaolin

From the present study the following conclusions can be drawn:

- The compressive strength of concrete with replacement of fly ash with cement results in increased strength compared to the normal.
- The split tensile strength and flexural strength increased on increment of fly ash.
- The inclusion of Metakaolin results in faster early age strength development of concrete.
- As the Metakaolin content increases the compressive strength, split tensile strength and flexural strength gets increased
- Considering the combined effect of fly ash and Metakaolin the compressive strength gradually reduces with increasing the percentage of fly ash replacement and increases gradually by addition of Metakaolin
- The utilization of supplementary cementitious material like Metakaolin in concrete can compensate for environmental, technical and economic issues caused by cement production.

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