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Review Paper on Use of Waste Metakaolin and Rice Husk Ash in Concrete

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ABTRACT

One essential material for the construction sector is concrete. Concrete usage is relatively high in emerging countries due to infrastructure development. In order to fulfil the criteria, a significant amount of cement is also consumed. Therefore, it is necessary to take care of the additional or substitute materials for the coarse, fine, and cement aggregate. The goal of the current endeavour is to address the additional materials in the concrete.

The two most well-known pozzolona that are used extensively in concrete projects are metakaolin (MK) and rice husk ash (RHA). Pozzolana is used to improve the qualities of cement and mortar. There are currently very few published publications that examine the independent execution of MK and RHA in mixed cement. Nonetheless, a small number of limited articles are available in the area of joint MK and RHA execution.

Key words: Supplementary Materials, Concrete, Non – Destructive test, Compressive Strength, Split Tensile Strength, Flexural Strength, Rebound hammer, Ultrasonic Pulse Velocity.

1. Introduction

Concrete is the most widely utilised man-made building material worldwide. These days, concrete is used extensively since the global building sector is expanding so quickly. Concrete is made up of a fixed amount of water, fine and coarse aggregate, and cement that is mixed to the right strength at the right age. The ingredients of concrete come from several sources and have varying physical, chemical, and reactive properties. Studying the qualities of concrete and its ingredients is necessary for this. Concrete usage has expanded considerably as a result of recent advancements in the building industry. After water, it is currently the second most consumed material worldwide. Cement and other raw materials are in high demand as a result of the enormous volume of concrete being used. As a result, the annual demand for cement worldwide has increased to between 5 and 7 billion metric tonnes. Natural resources (limestone) are depleting more quickly throughout the OPC production process, and the calcination of cement releases large amounts of greenhouse gases into the sky. Approximately 7% to 8% of man-made CO_2 emissions are discharged into the atmosphere during the cement manufacturing process.

Metakaolin

When compared to ordinary Portland cement (OPC) alone, metakaolin can be used as an accelerator and to fill in the spaces between the grains of cement as they react with $Ca(OH)_2$, which is created during the cement hydration process. This further activates the process of mineralization and greatly improves the mechanical and microstructural characteristics of concrete

Rice Husk Ash

Rice husks are the hard protective coverings of rice grains which are separated from the grains during milling process. Rice husk is an abundantly available waste material in all rice producing countries, and it contains about 30%–50% of organic carbon

2. Literature Review

Arfath Khan et al. (2013) postulated that the M60 concrete mixes with blended admixtures of condensed silica fume and metakaolin were discovered to have a compaction factor of 0.89 to 0.76 with a water cement ratio of 0.33 and with an addition of a maximum of 2% superplasticizer. The test resulted in lower slump and compaction factor values as the overall amount of blended CSF and MK admixtures increased.

When concrete containing MK was tested for workability, Paiva et al. (2012) found that the concrete's workability was reduced. The use of a wide variety of water-reducing admixtures caused the MK particles to defloculate, which ultimately improved their dispersion.

According to research by Kartini et al. (2008), as the RHA measure increases, so does the amount of water needed to keep the blends workable and improve their fluidity and consistency. Because of the adsorptive nature of the cellular RHA particles and their great fineness, concrete containing RHA needed more water to achieve a certain consistency, increasing its specific surface area.

According to Mahmud et al. (2003), different amounts of superplasticizer were anticipated to keep concrete workable within a 200–240 mm slump range. When superplasticizer (SP) is added to mixed OPC/RHA/MK mixtures, the replacement blends need a larger dose of SP than the addition mixes, but the blends with more MK require less SP to get comparable slump.

According to Khatri et al. (1995), the degree of cement replacement, the water-binder ratio, and the properties of the particles all had a significant impact on workability. High reactive metakaolin, silica fumes, and rice husk ash often increase cohesiveness, making the resulting concrete blend stickier and gluey. To achieve a reasonable workability, a larger dose of high range water reducer was needed.

In order to understand the impacts of using metakaolin and rice husk ash as a partial substitute for cement and polypropylene as an addition on the mechanical and water-absorbing qualities of mortar, Mohseni et al. (2017) investigated the experimental investigation. Different replacement ratios of metakaolin (5–15%) and rice husk ash (10–30%) by weight of cement were used to manufacture cement mortar. The percentage of polypropylene fibre utilised was 0.3%. Based on the findings, it was determined that 0.3% polypropylene fibre, 10% rice husk ash, and 10% metakaolin demonstrated superior mechanical qualities and durability.

"The strength of M20 grade concrete at the age of 28 days is obtained as 30.75N/mm2 with 5% replacement of rice husk ash and 5% replacement of metakaolin with recycled coarse aggregate," Vijaya Sekher Reddy et al. (2016) reported.

In order to determine the impact of metakaolin and silica fume on the mechanical characteristics of high performance concrete, Suresh Reddy et al. (2015) conducted research. Based on the experimental findings, the best ratio of metakaolin to silica fume, when used to partially replace cement in M50 grade concrete, is determined to be 12.5% and 7.5% by weight of cement, respectively.

When compared to their control concrete, Rajkumar et al. (2015)'s investigation into the combination of replacements for both metakaolin and copper slag produced significantly improved results in terms of compressive strength. The increase in strength is approximately 40% greater than the control concrete, and in certain unique cases (10% MK & 50% slag, 15% MK & 50% slag), it is observed to be approximately 80% greater.

According to Arfath Khan et al. (2013), the inclusion of metakaolin and silica fume increased the strength of concrete at 28 days of age in varying amounts. For M60, the strength increase was between 2.01% and 20.94%, and for M80, it was between 2% and 10.36%. Upon dissecting the test specimens, it is seen that the concrete materials exhibit a better grade of bonding. When compared to a typical blend, the blended admixtures of 10% CSF and 5% MK, partially replaced by cement weight, showed a significant increase in strength of 20.94% and 10.36%. Beyond the combination of 10% CSF and 5% MK in the M80 concrete mix, the blended mix proportions showed a diminishing trend in compressive strength, indicating the least strength of 87 N/mm2. Nevertheless, the blended mix proportions still showed higher strength and an expansion of 3.67% than the regular blend without admixtures.

In their 2012 study, Kannan et al. investigated the impacts of using metakaolin, rice husk ash, and their mixtures in place of cement mixing components. We investigated the compressive strength and saturation water absorption of mixed cement mortar. When rice husk ash and metakaolin were combined in a 1:1 ratio, the percentage increase in compressive strength was 20.9% at 15% replacement, 17.42% at 25% replacement, and 24.61% at 30% replacement. When substituting metakaolin for 25% of the rice husk ash, water absorption was 25%, 37.58%, and 37.5%, respectively, when substituting metakaolin for 25%, 25%, and 40% of the rice husk ash.

Erhan Guneyisi et al. (2012) conducted research to determine the impact of silica fume and metakaolin on the mechanical characteristics, durability associated with shrinkage, and permeability of high performance concrete. For a range of water cement ratios, the experimental results showed a striking increase in the compressive strength characteristics of blended concrete when compared to the control mix.

According to Vikas Srivastava et al. (2012), silica fume and metakaolin together are a suitable mixture for concrete manufacturing. It was found that the ideal combination dose for metakaolin and silica fume was 15% and 6% (by weight), respectively. On days 7, 14, and 28, the specimens were cast and put to the test. For the most part, the metakaolin content of the concrete increased with the 28-day compressive strength of the silica fume level. For every silica fume concentration, it was discovered that the concrete's compressive strength on the seventh day decreased as the metakaolin content increased.

Muthupriya et al. (2011) evaluated whether high performance reinforced concrete (HPRC) columns were appropriate for structural applications by conducting an experimental study on the behaviour of HPRC columns. Metakaolin and fly ash were used to partially substitute regular Portland cement in the preparation of high performance concrete. Test results showed improvements in strength, brittleness, and durability. The optimal replacement amount of fly ash and metakaolin was determined to be 7.5%, and the HPC concrete with 7.5% metakaolin had a compressive strength that was 12% greater than regular concrete.

In order to complete a near report, Justice J.M. et al. (2005) substituted metakaolin and silica fume for 8% of the cement by weight. The inclusion of metakaolin was beneficial, resulting in concrete that was noticeably stronger and more durable than typical mixtures. It was more practical to use finer metakaolin than coarser metakaolin to improve the characteristics of concrete. The use of superplasticizers was increased by the inclusion of metakaolin, which also showed improvements from the strength perspectives.

According to research done in 2012 by Vijaya Sekhar Reddy et al., adding 20% fly ash and 13.2% metakaolin to M80 high performance concrete results in very low quick chloride penetration values, with a water cement ratio of 0.261 and 0.283, respectively.

The effects of metakaolin and fly ash on the strength and durability of concrete were determined by Pacheco Torgal et al. (2011). Three techniques were used to assess the durability: concrete resistivity, oxygen permeability, and water absorption. They explained that a mix created with 100% Portland cement nevertheless exhibits a faster decline in early age compressive strength than a blend prepared with 30% Portland cement.

In comparison to the control mix with w/b = 0.35 (59%, 31%, 39%, and 104% respectively), the blends containing 50% slag, 35% fly ash, 20% and 30% RHA, and w/b = 0.65 exhibit increased electrical resistivity, according to Gastaldini et al. (2009).

According to Saraswathy et al. (2007), RHA can replace up to 30% of the cement in concrete and have an impact on its porosity and water absorption. The porosity values decreased as the RHA concentration increased. The volume of the bigger pores was reduced as a result of the tiny RHA particles increasing the matrix's particle packing density. Similarly, the RHA concrete's coefficient of water absorption was almost half that of the control concrete.

Experimental research by Jian-Tong Ding et al. (2002) revealed the effects of silica fume and metakaolin on the characteristics of concrete. It has been studied how metakaolin, also known as silica fume, affects the workability, strength, shrinkage, and resistance of concrete to chloride penetration. It was discovered that adding metakaolin and silica fume to concrete reduced the amount of shrinkage that occurred during the free drying process and the breadth of the shrinkage cracks. It is also shown that the chloride dispersion rate in concrete may be considerably reduced by adding metakaolin or silica fume.

In their experimental study, Ha Thanh Le et al. (2014) investigated the effects of varying levels of RHA as a partial replacement of cement in High Performance fine-grained concrete. They hypothesised that as the RHA content increased, the workability of the concrete blend decreased because RHA is a permeable material that causes the macro- and meso-pores of the particles to produce large specific surface area.

Kartini (2011) postulated that increasing the RHA content in a concrete blend will increase its workability. The absorptive nature of the cellular RHA particles and their great fineness mean that concrete containing RHA needs more water to achieve a given consistency. Therefore, a suitable dosage of superplasticizer should be used to improve the blend's convenience of use and uniformity as well as to maintain the blends' workability in terms of slump of 100mm to 150mm.

The effects of metakaolin and calcinedkaolins on concrete were examined by Mermerdas K et al. (2012) in their study "Strength development of concretes incorporated with metakaolin and different types of calcinedkaolins." In order to do this, unpurified ground kaolins from various sources were thermally processed under predetermined circumstances. For comparison, metakaolin from the Czech Republic that is sold commercially was utilised. For the purpose of making concrete, replacement amounts of metakaolin and calcinedkaolin (5%, 10%, 15%, and 20%) were allocated. As a baseline, one unadulterated blend without any additives was created. The concretes' compressive strengths were measured at 3, 7, 28, and 90 days. The statistical method known as GLMANOVA was used to assess how concrete's strength developed. A prediction model was developed using gene expression programming to assess the factors influencing the strength. The characteristics that were examined were the concentrations of SiO_2, Al_2O_3, kaolinite, and alunite, the fineness of the mineral admixture, the age of the concrete, and the replacement level. The results of the experimental studies demonstrated the significant influence that age, replacement level, and type of thermally treated kaolin had on the development of concrete strength. When the experimental data were compared with the seven parameters in the prediction model, it was shown to be a useful tool for evaluating the compressive strength of concrete that included commercial metakaolin and calcinedkaolins.

The performance of concrete mixtures containing local metakaolin is examined in Ramezanianpour A.A. et al.'s (2012) paper, "Influence of metakaolin as supplementary cementing material on strength and durability of concretes," with respect to compressive strength, water penetration, sorptivity, salt ponding, Rapid Chloride Permeability Test (RCPT), and electrical resistivity at 7, 28, 90, and 180 days. Through the use of XRD and SEM testing, the microstructure of the cement pastes containing metakaolin was examined. In this study, metakaolin is substituted for PC in the following mass percentages: 0%, 10%, 12.5%, and 15%. Water to binder (w/b) ratios are 0.35, 0.4, and 0.5, with a constant 400 kg/m3 total binder content. The results indicate that metakaolin increased the compressive strength of the concrete, decreased chloride diffusion, and improved the durability of the concrete. The connection between concrete's compressive strength and chloride permeability is exponential. A noteworthy linear correlation was seen between the outcomes of the salt ponding test and the Rapid Chloride Permeability Test.

In their study "Metakaolin as cementitious material: History, scours, production and composition –A comprehensive overview," Rashad A. M. et al. (2013) provide a summary of earlier research on kaolin. Kaolin can meet the needs of the paper, ceramic, and filler sectors globally. After receiving the appropriate heat treatment, kaolin transforms into metakaolin, a pozzolanic substance. Investigations have shown that metakaolin may be added to concrete and mortar to improve their qualities. It can also be utilised as a source of cementing ingredients for geopolymer or alkali activation.

Chloride diffusion and permeability in concrete containing metakaolin were examined by Hossam S. et al. (2016) in their study "Time-dependence of chloride diffusion for concrete containing metakaolin." Tests were conducted on fifty-three concrete mixes using a revised statistical technique. Utilising the enhanced response surface method (RSM), the most important variables influencing the diffusion of chloride at various ages were presented. The mixtures under examination included different ratios of water to binder (W/B) (0.3–0.5), replacement of metakaolin (MK) (0–25%), and total binder content (350–600 kg/m3). Based on the error function solution to Fick's law, a bulk diffusion test was used for two years to find the time-dependent coefficient m of chloride diffusion for all mixtures. The total and average techniques of the bulk diffusion test were used to get this coefficient. To help designers and engineers optimise mixture proportions, design charts were created. The study also examined several experimental correlations between the findings of the compressive strength, chloride diffusion coefficient, and rapid chloride permeability test (RCPT). The findings demonstrated that there was a general decrease in testing duration from 28 days to 760 days based on the values of the chloride diffusion. The results showed that the chloride diffusion reduction coefficients, mtotal and mavr, rose when the percentage of MK or binder content increased or as the W/B ratio decreased. The statistical model's analysis of variance (ANOVA) revealed that the W/B ratio was the most important factor influencing the chloride diffusion at early ages (28 and 90 days), whereas MK was the most significant factor impacting the chloride diffusion at late ages (360 and 720 days). Additionally, the proposed models and design charts in this work are particularly useful for assisting in the service life forecast of concrete that contains MK.

In their work "Strengthening of concrete by partial replacement of cement with fly ash and Metakaolin mix," Teja Kiran Ch et al. (2016) examine the impact of mineral admixtures combined with cement replacement while maintaining the same water-to-cement ratio for both regular and modified concrete. The optimal ratio for achieving the highest strength was found by partially replacing cement with fly ash and metakaolin in amounts of 0, 5, 10, 15, 20, and 30%. M20 grade concrete mix was utilised for the experimental study. Testing was done on the concrete's flexural and compressive strengths. The ideal proportion for both compressive and flexural strength was found by combining the ideal percentages of the two components, which were found to be Metakaolin alone and fly ash alone. After seven and twenty-eight days of curing, the specimens, cubes, and beams underwent testing. The outcomes of the changed concrete and the control specimen were compared.

The improvement of Rice Husk Ash concrete's mechanical qualities by the use of superplasticizer was documented by Kartini et al. (2008). Because RHA concrete required more water for comparable workability, it achieved a lower compressive strength without superplasticizer than the control concrete.

In 2021, Chen Xupeng, Sun Zhuowen, and Pang Jianyong investigated the effects of metakaolin (MK) on the durability of concrete when it was exposed to joint corrosion of SO4 2−, Mg2+, and Cl−.

3. Conclusion

Because of the need for environmental preservation and sustainable building practices going forward, the usage of by-products such fly ash, granulated blast furnace slag, silica fume, rice husk ash and metakaolin in cement and concrete has become increasingly important.

A lot of research has been done recently on the use of metakaolin (MK) in concrete and mortar as a partial replacement for cement. The studied literature unequivocally shows that MK is a potent pozzolan.

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