Implication of Metakaolin in Quarry Dust Concrete

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***Abstract*—The utilization of well graded, fines free quarry dust has been accepted as a building material in the construction industry in recent years and it has been used as an alternative material to river sand for fine aggregate. The use of supplementary cementitious materials such as fly ash, silica fume, slag and metakaolin in concrete improves workability, reduces the heat of hydration, minimizes cement consumption and enhances strength and durability properties by reducing the porosity due to the pozzolonic reaction. Metakaolin is a highly pozzolanic and reactive material. In this paper emphasize has been given to metakaolin as partial replacement of cement at 5%, 10%, 15% and 20% by weight of cement in concrete having quarry dust as fine aggregate. The effect of metakaolin on the strength properties was analyzed by conducting compressive, split tensile and flexural strength tests and durability properties were evaluated by impressed voltage measurement, rapid chloride penetration test (RCPT) and gravimetric weight loss measurement in addition to water absorption and bulk density analysis. The optimum percentage of metakaolin replacement was also determined.**

***Index Terms*—concrete, quarry dust, metakaolin, strength, durability, corrosion resistance**

I. Introduction

Quarry dust is usually used in large scale in the highways as a surface finishing material and manufacture of lightweight aggregates, bricks, tiles and autoclave blocks (Radhikesh et al 2010). Use of quarry dust as fine aggregate in concrete draws serious attention of many researchers and investigators (Hameed and Sekar 2009, Ahmed 1989). A complete replacement of quarry dust to river sand as fine aggregate in concrete is possible with proper treatment of quarry dust before utilization (Illangovan et al 2008).The utilization of well graded, fines free quarry dust has been accepted as building material in the industrially advanced countries (Manasseh Joel 2010, Hudson 1997) and the concrete containing quarry dust as fine aggregate is promising greater strength, lower permeability and greater density which enable it to provide better resistance to freeze/thaw cycles and durability in adverse environment (Sahu et al 2003 PrakashRao and Gridhar 2004).

Mineral admixtures such as fly ash, silica fume, slag and metakaolin are finely divided siliceous materials which are added to concrete in relatively large amounts, generally in the range of 20 to 50% by weight of Portland cement (Cyr et al 2006, Swamy 1986). Since some of these materials are cheaper than Portland cement, there is an economic advantage in wider use and also utilization of these materials reduces environmental load due to disposal problems (Sarkar 1994, Dias et al 2003). In fresh concrete these materials improve workability and reduce the heat of hydration and cement consumption, whereas in hardened concrete reduce the porosity by the pozzolonic reaction (Safiuddin et al 2001, Zang 1999) Metakaolin which is obtained by thermally treated kaolin is a pozzolanic material which is having similar properties of cement. Metakaolin combines with calcium hydroxide to produce additional cementing compounds. Particularly utilization of metakaolin in concrete enhances the pore structure of the concrete and makes impervious concrete thus increasing the strength and durability (Sabir et al 2001). The main objective of this experimental investigation is to study the effect of partial replacement of cement with metakaolin by various percentages as 5%, 10%, 15% and 20% in concrete containing quarry dust as a complete substitute for fine aggregate and to determine the optimal percentage of metakaolin to obtain maximum strength and durability properties.

II. Experimental Procedure

A. Materials Used

Ordinary Portland Cement (43 Grade) was used throughout the investigation. Locally available well-graded quarry dust, conforming to Zone-II having specific gravity 2.68 and fineness modulus 2.70 was used as fine aggregate. Metakaolin with specific gravity 2.5 was used to replace cement at 5%, 10%, 15% and 20% by weight of cement. Natural granite aggregate having density of 2700kg/m3, specific gravity 2.7and fineness modulus 4.33 was used as coarse aggregate. High yield strength deformed bars of diameter 16mm was used for pullout and corrosion tests. To attain strength of 20 N/mm^2, a mix proportion was designed based on IS 10262-1982 and SP23:1982(21). The mixture was 1:1.52:3.38 with water cement ratio 0.45.

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B. Methodology

Concrete cubes of size 150 x 150 x150mm, beams of size 500 x 100 x 100 mm, cylinders of size 150mm diameter and 300 mm long were cast for compressive, flexural and split tensile strength tests. After 3, 7, 28, and 90days curing the specimens were tested as per IS: 516 – 1964. Water absorption of hardened concrete specimens was calculated based on ASTM C642-81. Concrete cylinders of size 75 mm diameter and 150 mm length with centrally embedded a high yield strength deformed(HYSD) steel bar of 16mm diameter were used to assess the corrosion protection efficiency under accelerated test conditions and weight loss measurement. After 90 days curing the specimens were subjected to acceleration corrosion process in order to accelerate reinforcement corrosion in the saline media (3% Sodium chloride) under a constant voltage of 6 volts from the D.C power pack. For weight loss measurement the cylinders were immersed in 3% NaCl solution under alternate wetting (3days) and drying (3days) conditions over a period of 90 days. At the end of 90days the cylinders were broke open and the final weight of the specimens was taken and the loss in weight was calculated. From the weight loss obtained corrosion rate is calculated. The RCPT is performed by monitoring the amount of electrical current that passes through concrete discs of 50mm thickness and 100mm diameter for a period of six hours. A voltage of 60 V DC is maintained across the ends of the specimen throughout the test. One lead is immersed in a sodium chloride(NaCl) solution(0.5N) and the other in a sodium hydroxide(NaOH) solution (0.3). The total charge passed through the cell in coulombs has been found in order to determine the resistance of the specimen to chloride ion penetration.

III. Results and Discussion

A. Strength Tests

The implication of metakaolin in quarry dust concrete in terms of strength and corrosion resistive properties was investigated by various experiments and the results are discussed below. The compressive, split tensile and flexural strength results obtained after 3, 7, 28 and 90 days are shown in Fig. 1 to Fig. 3.

From the Fig. 1, it is evident that 5% addition of metakaolin shows 9% increase in the compressive strength, 10% shows 14.5 % improvement while the addition of 15% gives hike of 23% and this yields the maximum increase in the strength value. Further, addition of metakaolin to 20% yields a comparatively lower value by 11%. Similarly, the addition of metakaolin gives the maximum increase in split tensile strength at 15% replacement (Fig. 2) and the increase in strength value is 21. 6%. In accordance with Fig. 3, it is understood that addition of 15% of metakaolin shows the maximum increase in the flexural strength value by 20.8%.

The strength test results revealed thatthe strength values of metakaolin blended quarry dust concrete specimensare increasing consistently with time and the magnitude of the strength is more than the control specimen for all percentages of metakaolin. This is because the addition of metakaolin to concrete results in an improved bond between the hydrated cement matrix and the sand in the mix, hence increasing strength. It was found that 15% replacement appears to be the optimum replacement where concrete exhibits enhanced strength values at all ages when compared to the control specimen.

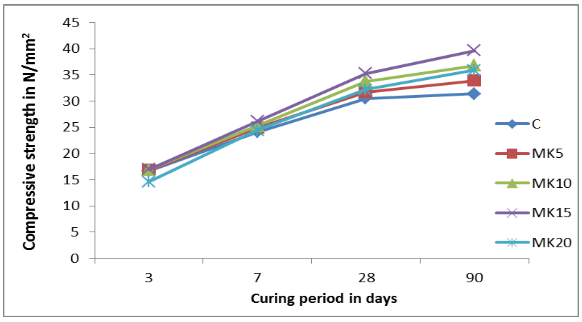

Figure. 1. Compressive strength development

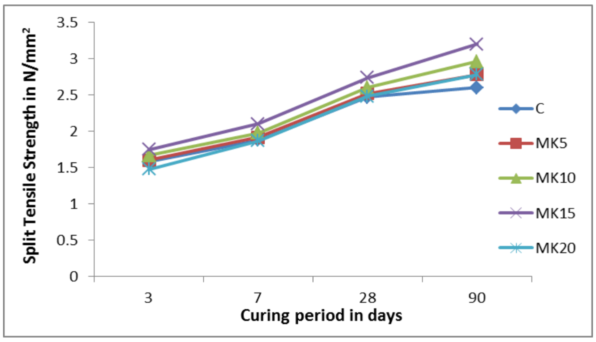

Figure. 2. Split tensile strength development

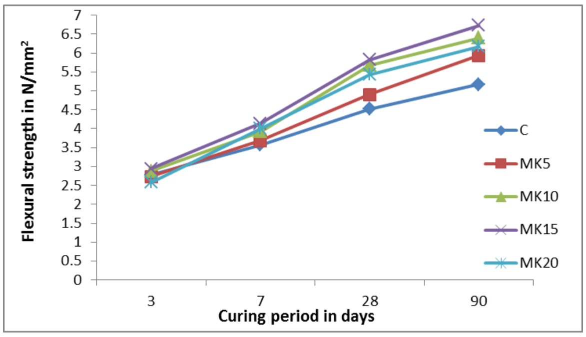

Figure. 3. Flexural strength development

IV. Water Absorption and Bulk density

The results of water absorption and bulk density tests conducted on the quarry dust concrete and metakaolin blended quarrydust concrete specimens are shown in Fig. 4 and Fig. 5.

The test values obtained on the micro structural properties of metakaolin blended quarry dust concrete specimens proved that, the increase in metakaolin percentages, resulting in lower water absorption and improved bulk density. This is because, the use of metakaolin in concrete reduces the excessive bleeding by increasing overall paste volume which results in denser and impervious concrete, thereby helping to uphold greater density.

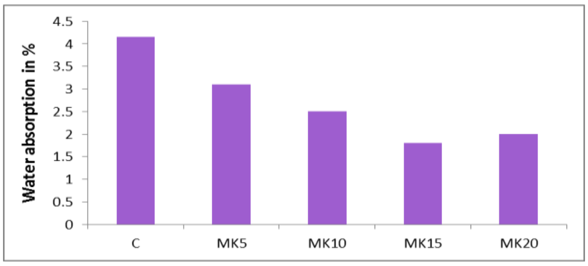

Figure. 4. Water absorption performance

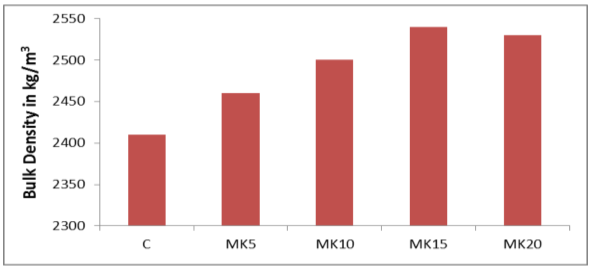

Figure. 5. Bulk density improvement

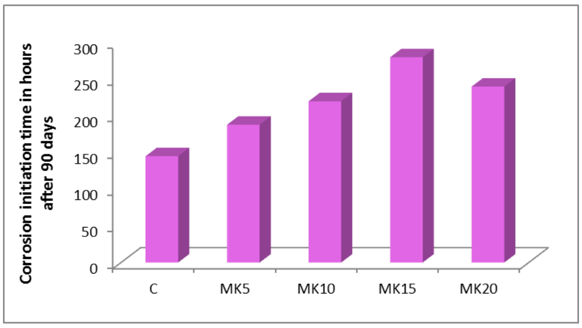

Figure. 6. Corrosion initiation time

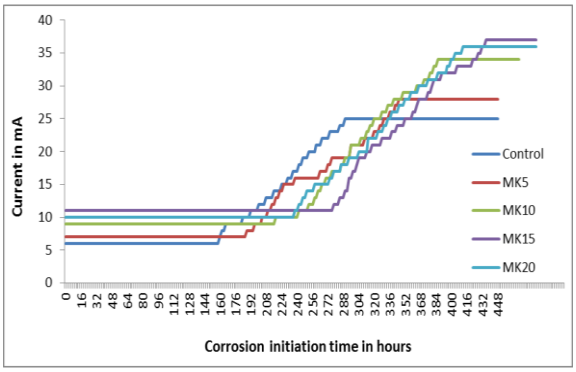

Figure. 7. Current intensity Vs corrosion initiation time.

V. Durability Tests

A. *Impressed Voltage Test*

Corrosion resistance performance of metakaolin blended quarry dust concrete was investigated by means of impressed voltage technique. The corrosion initiation time and the current intensity with respect to corrosion initiation time of quarry dust concrete with various percentages of metakaolin have shown in Fig. 6 and Fig. 7.

It is found from Fig. 6 that the time to initiate corrosion for quarry dust concrete was found to be 160 hours. Quarry dust concrete with 5%, 10%, 15% and 20% replacement of cement by metakaolin shows better corrosion resistance when compared with quarry dust concrete without metakaolin. Results revealed that the increase in the corrosion resistance for 5% to 20% replacement are found to be 18%, 23%, 40% and 30% respectively This is because addition of metakaolin reduces the permeability due to filler effect of metakaolin in concrete. Moreover metakaolin has significant influence on the rate of accelerated hydration and the pozzolanic reaction. Because of its pozzalonic nature, it becomes a part of the cementitious matrix and influences the durability.

B. *Rapid Chloride Penetration Test (RCPT)*

Chloride diffusion results of the different percentages of metakaolin are displayed in Fig. 8. The chloride ion penetration capacity of the specimens with various percentages ofmetakaolin is discussed here.

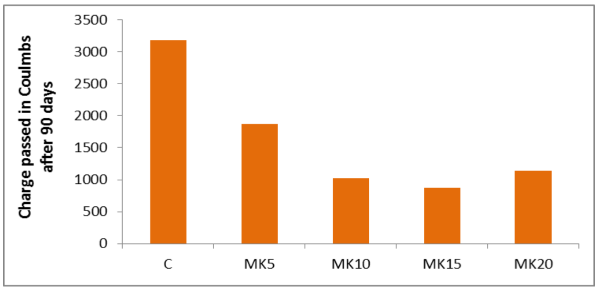

Figure. 8. Rapid chloride penetration test

The performance of the quarry dust concrete with 5%, 10%, 15% and 20% replacement of cement by metakaolin are observed to be 1.25, 1.7, 2.4 and 1.5 times greater than the control specimen. This is because of the transformation of large pores to fine pores as a consequence of the pozzolanic reaction between cement paste and metakaolin which substantially reduces the permeability in the cementitious matrix. Thus metakaolin blended cement concrete is found to be more effective in limiting chloride diffusion than normal concrete.

C. *Weight Loss Measurement*

Fig. 9 demonstrates average corrosion rate calculated in mmpy for various percentages of metakaolin from weight loss measurements.

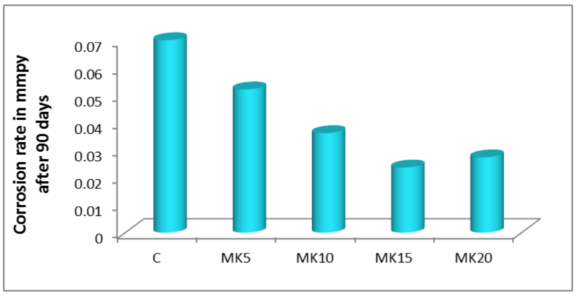

Figure. 9. Corrosion rate in mmpy

The corrosion rate of the specimens with 5%, 10%, 15% and 20% metakaolin have provedthat the corrosion rate is drastically reducedwith increase in percentage of metakaolin which represents thatthe metakaolin blended quarry dust concrete can be used in chloride laden areas with better corrosion resistive properties. From the figure it is inferred that 15% replacement of metakaolin show the lowest corrosion rate values. The same trend was observed in impressed voltage test and RCPT test also.

VI. Conclusion

- The inclusion of metakaolin in quarry dust concrete has positive impact on the rheological properties in terms of workability, compactability, bleeding and segregation
- The strength test results show that the strength development of quarry dust concrete blended with metakaolin is found to be enhanced.It was observed that 15% replacement is the optimum replacement where concrete exhibits enhanced strengths and corrosion resistance at all ages.
- Metakaolin combines with calcium hydroxide to produce additional cementing compounds and thereby improving pore structure of the concrete. Due to additional pozzolanic reaction the impermeability and density of the concrete in greatly improved and offers excellent corrosion resistance.
- Finishing is quite easier when metakaolin is incorporated in quarry dust concrete.
- From the results of strength and durability tests it is concluded that 15% of metakaolin blended quarry dust concrete can be magnificently and economically used in the construction industry

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