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Strength Characteristics of Concrete Containing Metakaolin and GGBS- A Review

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Abstract— Cement consumption in the world has increased exponentially since 1926 and is continuing to increase because of its scale of consumption and manufacture. Cement production in 2003 was approximately1.2 billion tonnes/year and this was expected to grow to about 3.5 billion tonnes/year by 20151. The reason for this reflects population growth and global developments in infrastructure and the excellent mechanical and durability properties that concrete provides. In this paper deals with study the applicability, performance, availability, complexity & the effect of using local calcined kaolin or MK obtained commercially as pozzolana on the development of high strength and permeability/durability characteristics of concrete designed for a very low w/b ratio of 0.4 & also the purpose of establishing standard procedures for Destructive testing & non destructive testing (NDT) of concrete cubes & cylinders is to qualify and quantify the material properties of in-situ concrete with intrusively examining the material properties. In addition, the optimum replacements with respect to strength and durability were determined by varying the amount of Metakaolin & Ground Granulated Blast Slag (GGBS) as partial cement & fine aggregates replacement. Thus to make concrete sustainable in the Indian context a multiprong strategy should be adopted.

Keywords—Mechanical and Durability Properties, High Strength, Metakaolin, Ground Granulated Blast Slag.

I. Introduction

The sustainable development for construction involves the use of nonconventional and innovative materials, and recycling of waste materials in order to compensate the lack of natural resources and to find alternative ways conserving the environment. Concrete is the most widely used building material, with more than 10 billion tonnes produced annually by the construction industry worldwide, hence there is need to look into its sustainability, which finds wider application in the construction industry. Concrete structures are maintenance free when compared to steel structures. Concrete is the most widely used construction material in civil engineering industry because of its high structural strength, stability, and malleability. Concrete produced amounted to 1 m3 per person. Thus, even though concrete has low embodied energy per unit mass, yet it contributes to maximum embodied energy followed by steel. The ingredients of concrete are cement, sand, coarse aggregate and water.

Concrete is probably the most extensively used construction material in the world. However, when the high range water reducer or super plasticizer was invented and began to be used to decrease the water/cement (w/c) or water/binder (w/b) ratios rather than being exclusively used as fluid modifiers for normal-strength concretes, it was found that in addition to improvement in strength, concretes with very low w/c or w/b ratios also demonstrated other improved characteristics, such as higher fluidity, higher elastic modulus, higher flexural strength, lower permeability, improved abrasion resistance, and better durability. This fact led to the development of HPC. HPC is the latest development in concrete. It has become more popular these days and is being used in many prestigious projects such as Nuclear power projects, flyovers, multistoried buildings etc.

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II. Data collection

- Recently, as an alternative material to BFF, an artificial pozzolan material made of coal mines and coal ash, etc. which has similar characteristic to BFF, has been developed. This material is called Metakaolin-based artificial pozzolan (here in after called as "Metakaolin"). This material has been produced in Japan and growth in demand can be expected in the future. In this study, the long-term durability for three years exposure to actual marine environment has been examined with concretes made of ordinary Portland cement, ground granulated blast furnace slag and Metakaolin
- 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 (Basu et al. 2000; Tiwari and Bandyopadhyay 2003).
- Metakaolin has pozzolanic properties bringing positive effects on resulting properties of concrete. Pozzolanic properties cause chemical reaction of active components with calcium hydroxide (portlandite), which is formed as a product of cement hydration.
- Many researchers clearly demonstrated the development of structural properties of cement concrete blended with Metakaolin.
- Metakaolin (MK) or calcined kaolin, other type of pozzolan, produced by calcination has the capability to replace silica fume as an alternative material.
- Previously, researchers have shown a lot of interest in MK as it has been found to possess both poz-zolanic and microfiller characteristics (Poon et al. 2001; Wild and Khatib 1997; Wild et al. 1996).
- It has also been used suc-cessfully for the development of high strength self compacting concrete using mathematical modeling (Dvorkin et al. 2012). However, limited test data are

available regarding the perfor-mance of the commercially available MK and Indian cements in the case of high strength concrete in the country (Basu 2003; Basu et al. 2000, Pal et al. 2001, Patil and Kumbhar 2012)

 Nova John in 2013 examined the Strength properties of metakaolin admixed Concrete. This paper presents the results of an experimental investigations carried out to find the suitability of metakaolin in production of concrete. The referral concrete M30 was made using 53grade OPC and the other mixes were prepared by replacingpart of OPC with Metakaolin. The replacement levels were 5%, 10%, 15% up to 20 %(by weight) for Metakaolin. The various results which indicate the effect of replacement of cement by metakaolin on concrete are presented in this paperto draw useful conclusions. The results were compared with reference mix. Test results indicate that use of replacementcement by metakalion in concrete has improved performance of concrete up to 15%.

 Aiswarya S, Prince Arulraj G, Dilip C in 2013 examined a review on use of metakaolin in concrete.This paper reviews the use of metakaolin as supplementary cementations material in concrete. From the recent research works using Metakaolin, it is evident that it is a very effective pozzolanic material and it effectively enhances the strength parameters of concrete.

 Dojkov.I et al (2013) experimentally studied the reaction between Metakaolin-Ca(OH)2-water and Fly ash- Ca(OH)2-water.

 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.

 Sabir.B.B et al (2001) carried out a study on the utilization of Metakaolin as pozzolanic material for mortar and concrete and mentioned about the wide range application of Metakaolin in construction industry .They reported that the usage of Metakaolin as a pozzolana will help in the development of early strength and some improvement in long term strength. They mentioned that Metakaolin alters the pore structure in cement paste mortar and concrete and greatly improves its resistance to transportation of water and diffusion of harmful ions which lead to the degradation of the matrix.

 Poon et al. (2001) conducted studies on rate of pozzolanic reaction of metakaolin in cement pastes. The results obtained indicate that the rates of initial reactivity in metakaolin blended cement pastes were higher than in silica fume or fly ash blended cement pastes. Due to its high initial reactivity, metakaolin resulted in a higher rate of compressive strength development for cement pastes when compared with silica fume.

 Brooks and Joharis (2001) investigated the effect of metakaolin on creep and shrinkage of concrete. The studies revealed that the reduction in early age autogenous shrinkage is greater at higher replacement levels. Also, comparing with control concrete, greater part of the total shrinkage of the metakaolin concrete is considered to be autogenous shrinkage. This observation does not appear to be influenced by the replacement level. Total creep, basic creep and drying creep of the concrete are considerably reduced due to metakaolin inclusion particularly at higher replacement levels.

 Curcio et al. (1998) studied the effect of 15% replacement of cement in mortar with four metakaolin samples and compared to concrete containing silica fume. Results showed that in mortars using metakaolin samples, the compressive strength development at early stages is at a higher rate than that of silica fume. 10-15% replacement by metakaolin increases compressive strength at 14 days with respect to control sample by about 30% with OPC.

A. Permeability Decreases

A. Sadr Momtazi, Ranjbar. M. M, Balalaei. F, Nemati. R examined the effect of Iran's metakaolin in enhancing theconcrete compressive strength. This paper presents the performance of metakaolin (NCCM) on compressive strength and durability of concrete. Fired (Calcinated) NCCM has a very good pozzolanic, which could be partially replaced with Portland cement. It can decrease permeability, increase compressive strength and concrete durability. In this study, four different type of metakaolin which one of them was made in UK and the others were from different part of Iran were used. The results indicate that the replacing NCCM up to 20% has noticeable effect on compressive strength in comparing with mixture without metakaolin.

B. High Reactivity Metakaolin

B. B. Patil1, P. D. Kumbhar examined that " Strength and Durability Properties of High Performance Concrete incorporating High Reactivity Metakaolin" the present paper deals with the study of properties namely workability, compressive strength and durability of M60 grade HPC mixes incorporating different percentages of high reactivity metakaolin by weight of cement along with some suitable super plasticizer. The results of the study indicate that the workability and strength properties of HPC mixes improved by incorporating HRM up to a desirable content of 7.5% by weight of cement. HPC mixes have also indicated better resistance to the attacks of chemicals such as chlorides and sulfates when the HPC mixes were exposed to theses chemical for 180 days period.

C. Heat Of Hydration

Ambroise et al., 1994 [57], pointed the temperature rise of MK mortars relative to the plain OPC mortar showing an accelerating effect of MK on OPC hydration. Note that the maximum observed temperature rise occurs at 10% replacement of OPC by MK. The high reactivity of MK with Ca(OH)2 is the cause of increase in temperature.

D.Bleeding

Gebler and Klieger, 1986 [60], reported that concrete with FA showed less bleeding than plain concrete. Also, concrete with Class C FA showed lesser bleeding than concretes with Class F FA. The reduction in bleeding is due to greater surface area of particles of fly ash and lower water content with fly ash for a given workability [28]. On the contrary, concrete containing SF or RHA produces no bleeding water [24]. Similarly, the use of MK as a partial replacement of cement in suitably designed concrete mixes improves cohesion and reduces bleeding of fresh concrete

E. Interfacial Transition Zone

Saad et al., 1982 [13]; Larbi, 1991 [14]; Halliwell, 1992 [15]; and Hewlett, 2004 [16] reported that the inclusion of MK in concrete has no drawbacMartin [17] reported that the inclusion of MK in concrete increases the compressive strength up to 110 MPa (16 ksi) with superplasticizer to overcome the higher water requirement in MK concreteks; however, in 1995,. In 1996, Wild et al. [18] found that the optimum OPC replacement with MK is 20% by weight with superplasticizer of 2.4% of binder weight. Recently, Duan et al., 2013 [19], studied the pore structure and interfacial transition zone (ITZ) of concrete using GGBS, SF, and MK and it has been found that MK has positive effects on pore structure and ITZ enhancement of concrete higher than SF and GGBS [19]

F. Setting Time (High Early Strength)

Initial and final setting times of concrete containing 10% MK are increased and are extended further with the increase in replacement level; however, by increasing the replacement level up to 15%, minor drop in initial setting time particularly is observed in comparison with 10% MK concrete [61]. This might be due to the greater water demand of MK at the higher replacement level. With higher MK content, concrete due to higher binder phase becomes denser and results in accelerating the setting [61]; however, use of effective superplasticizer offsets the high water demand and low water content and ultimately increases the setting time

G.Reactivity

Reactivity of pozzolan may be compared with the help of Chapelle test. This test is performed by the reaction of calcium hydroxide with the dilute slurry of the pozzolan at a temperature of 95°C (203°F) for 18 hours. After reaction, the consumed calcium hydroxide is determined. Largent, 1978 [53], reported the results and showed that the reactivity of MK is higher than the other pozzolana. The authors conducted the same test on SF and MK as shown in Table 1 and verified the results reported by Largent, 1978. Larbi, 1991 [14], demonstrated that MK in a cement matrix eliminated the calcium hydroxide completely. Nevertheless, MK reduces the calcium hydroxide level in concrete but pH remains stable above 12.5

H.Resistance To Acid Attack

Beulah M. Asst Professor, Prahallada M. C. Professor, Effect Of Replacement Of Cement By Metakalion On TheProperties Of High Performance Concrete Subjected To Hydrochloric Acid Attack. This paper presents an experimental investigation on the effect of partial replacement of cement by metakalion by various percentages 0%,10%, 20%, and 30% on the properties of high performance concrete, when it is subjected to hydrochloric acid attack.The results were compared with reference mix. Test results indicate that use of replacement cement by metakalion in HPC has improved performance of concrete up to 10%.

I. Metakaolin As High Strength Concrete

Sanjay N. Patil, Anil K. Gupta, Subhash S. Deshpande is examined the Metakaolin- Pozzolanic Material for Cement in High Strength Concrete. This paper deals with the use of Metakaolin which is having good pozolanic activity and is a good material for the production high strength concrete, which is getting popularity because of its positive effect on various properties of concrete.

J. Reduced Sorpitivity

M. Si-Ahmed, A. Belakrouf, and S. Kenai examined that “Influence of Metakaolin on the Performance of Mortars and Concretes”. The experimental results have shown that the rates of Substitutions of 10 and 15% metakaolin increases the compressive strength and flexural strength at both early age and long term. The durability and the permeability were also improved by reducing the coefficient of sorptivity.

 Surveys conducted before [12-16] mainly focuses on characterizing single characteristics of concrete materials with single test technology, and very little work has been carried out on contrast different test technologies or evolution of the microstructure and durability of concrete incorporating various mineral admixtures including ground granulated blast furnace slag and metakaolin. This paper presents the results of a study on effects of ground granulated blast furnace slag and metakaolin on pore structure, ITZ, compressive strength and durability aspects of concrete and thermodynamic stability of hydrate phases.

 Very few researchers have addressed the problem of efflorescence in metakaolin cement-based composites. This study sought to determine the appropriate quantity of metakaolin required (as a replacement for cement) to reduce efflorescence. We employed specimens with various replacement ratios of metakaolin (0%, 5%, 10%, 15%, 20%, and 25%) at a water/cement (w/c) ratio of 0.5. The occurrence of white efflorescence was investigated under various curing environments, at the curing age of 3, 7, and 28 days.

 Metakaolin (MK) or calcined kaolin, other type of pozzolan, produced by calcination has the capability to replace silica fume as an alternative material. 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 (Basu et al. 2000; Tiwari and Bandyopadhyay 2003). At present the market price of MK in the country is about 3–4 times that of cement. In India, most of the good quality silica fume is imported and the cost is 9–10 times the cost of OPC. Therefore the use of metakaoiln proves economical over that of silica fume. Previously, researchers have shown a lot of interest in MK as it has been found to possess both poz-zolanic and microfiller characteristics (Poon et al. 2001; Wild and Khatib 1997; Wild et al. 1996). It has also been used suc-cessfully for the development of high strength self compacting concrete using mathematical modeling (Dvorkin et al. 2012). However, limited test data are available regarding the perfor-mance of the commercially available MK and Indian cements in the case of high strength concrete in the country (Basu 2003; Basu et al. 2000, Pal et al. 2001, Patil and Kumbhar 2012)

K. Ggbs

 Unlike FA in which Si–O–Si link has to break to make it reactive with lime, GGBS requires to be activated to react with lime. GGBS due to its glassy structure reacts very slowly with water in the presence of activators. Commonly, sulphates and/or alkalis act as activators, reacting chemically with the GGBS. These activators disturb the glassy structure and react to increase the pH of the system up to critical. In contrast to FA, GGBS only needs a pH level less than 12 and activators. In concrete, due to hydration of cement, Ca(OH)2 is produced and acts as an activator

 Similar to FA, less water content is required when GGBS is added. Generally, 25% to 70% of cement is replaced with GGBS in the concrete [41]. GGBS requires about 3% lesser water content in comparison to OPC for the equal slump requirement. This is due to the smooth surface texture of the slag particles that delay the chemical reaction and increase the setting time

 Oormila.T.R & T.V. Preethi (2014) carried out a study on soil characteristics was treated with various percentages of GGBS (15%, 20% & 25%) and Unconfined consolidated Compression test was performed. From the UCS value it was found that soil treated with 20% of GGBS gives the optimum strength when compared with the virgin soil with an increment of 73.79% for 21 days of curing.

 M.C.Nataraja (2013) investigates, shows that the compressive strength of cement mortar increases as the replacement level of GGBS increases. This increase is not substantial. However for 100% replacement the strength decreases marginally compared to 100% natural sand. From this it is clear that GGBS sand can be used as an alternative to natural sand from the point of view of strength. Use of GGBS upto 75% can be recommended

 A number of studies have been conducted concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using this waste material. This paper outlines the influence of Ground Granulated Blast furnace Slag (GGBS) as partial replacement of fine aggregate on mechanical properties of concrete. The strength of concrete is determined having OPC binder, replaced the fine aggregate with15%, 30%, 45% respectively. For this purpose, characteristics concrete mix of M25 with partial replacement of cement with GGBS is used and the strength of concrete cubes and cylinder have determined. The strength of concrete specimens has been compared with the reference specimen. Also X-ray diffraction (XRD) and scanning electron microscope (SEM) tests have been performed to examine the hydration products and the microstructure of the tested specimens. A correlation has been established between the developmental strength concrete with and without GGBS through analysis of hydration products and the microstructure.

 K.Ganesh Babu (2000) presented an effort to quantify the 28days cementatious efficiency of ground granulated blast furnace slag in concrete at the various replacement levels. The replacement levels in the concrete studied varied from 10% to 80% and the strength efficiencies at the 28days were calculated. Strength efficiency factor varied from 1.29 to 0.70 for percentage replacement levels varying from 10% to 80%.Overall the prediction of the strength of concretes varying from 20 to 100Mpa with GGBS levels varying from 10% to 80% by this method was found to result in a regression coefficient of 0.94 which was also the same for normal concretes.

 In 1862, GGBS was first discovered in Germany by Emil Langen; however, commercial production of lime¬ activated GGBS was started in 1865 in Germany [5]. Concrete containing GGBS has been named in the literature as slag concrete, which is being used successfully in many countries due to accepted benefits of this material and the use of slag concrete has been recommended in their national standards [5]. Around 1880, GGBS was first used with Portland cement (PC). Since then it has been used extensively in many European countries. In the UK, the first British standard for Portland blast furnace cement (PBFC) was introduced in 1923 [5].

 Author's previous research reported that concrete using GGBS cement which consists of ground granulated blast furnace slag and ordinary Portland cement has high resistance to chloride attack, chemical erosion and other deteriorations (Matsumoto, 2009). On the other hand, GGBS concrete has some disadvantages comparing to ordinary Portland cement concrete, such as lower initial strength and higher dry shrinkage. Therefore, for wider use of GGBS in the construction field of concrete structures, it is necessary to avoid such problems. In order to solve those problems, blast furnace fume (here in after called "BFF") was firstly tried to examined in our research works. BFF is obtained by collecting the gas dischargedfrom small blast furnaces in China. It has reactivity like as pozzolan, which can be expected to generate Calcium Silicate Hydrates and Calcium Aluminate Hydrates by its rapid reaction with Ca(OH)2 in GGBS concrete during early age. According to previous experimental results, it is possible to improve not only the initial strength (Numata, 2007) but also resistance against chloride penetration of

GGBS concrete by adding BFF (Umeki, 2009). However, continuous produce of BFF cannot be expected anymore, because of reduction of the gas emission from the blast furnaces in China due to recent modernization of the system.

This is beneficial in large concrete pouring that enable reduced temperature rise which will reduce the probability of thermal cracking .

M. Setting Time

Since GGBS slowly reacts with water as compared to Portland cement, therefore stiffening/setting time of concrete is high. The setting time will be greater at high replacement levels above 50% and at lower temperatures (below 10°C (50°F).

III. Conclusion

A. Metakaolin

- It shows that optimal performance is achieved by replacing 7% to 15% of the cement with metakaolin. While it is possible to use less, the benefits are not fully realized until at least 10% metakaolin is used.
- Values of compressive strength of concrete with metakaolin after 28 days can be higher by 20%.
- Dosage of 15% of metakaolin causes decrease of workability of suspension in time. Increasing amount of percentual proportion of metakaolin in concrete mix seems to require higher dosage of superplasticizer to ensure longer period of workability.
- Metakaolin has highly pozzolanic properties, that it could be used as an scm.
- Metakaolin is increasingly being used to produce materials with higher strength, denser microstructure, lower porosity, higher resistance to ions, and improved durability.
- Metakaolin (mk) or calcined kaolin, has the capability to replace silica fume as an alternative material.
- Mk as it has been found to possess both poz-zolanic and microfiller characteristics.

it is a chemically active mineral admixtures (highly reactive pozzolan) e.g. : mk

- Increase the cohesiveness of concrete & require more water to maintain workability however, the requirement of water may be offset by adding plasticizer.
- The water demand depends on the particle size, specific surface area, particle shape, replacement level, and reactivity of particular mineral admixture.
- Heat of hydration increases with the use of chemically active mineral admixtures
- Initial and final setting times of concrete decrease with the use of chemically active mineral admixtures and increases with the increase of microfiller mineral admixtures.
- Mk has positive effects on pore structure and itz (interfacial transition zone) enhancement of concrete higher than sf and GGBS
- It have greater resistance to efflorescence since 20% is maximum for strength development.

L. Heat of Hydration

According to Woolley and Conlin, 1989 [54], and Keck and Riggs, 1997 [55], Similar to FA, as the proportion of GGBS is increased; the heat of hydration is reduced.

- The strength development of metakaolin concrete was evaluated using the efficiency factor (k value) which is high (close to 3.0 at 28 days) (high reactive pozzolona) lead to concrete production with excellent performance.
- When compared with cement, the use of metakaolin may be uneconomical due to its high cost whereas it is economical in the aspects of durability and strength.
- Metakaolin as a pozzolana will help in the development of early strength and improvement in long term strength.
- Metakaolin alters the pore structure in cement paste mortar and concrete and greatly improves its resistance to transportation of water and diffusion of harmful ions which lead to the degradation of the matrix.
- Due to its high initial reactivity, metakaolin resulted in a higher rate of compressive strength at early stages development for cement pastes when compared with silica fume. 10-15% replacement by metakaolin increases compressive strength at 14 days with respect to control sample by about 30% with opc.
- The studies revealed that the reduction in early age autogenous shrinkage is greater at higher replacement levels & total creep, basic creep and drying creep of the concrete are reduced due to metakaolin inclusion particularly at higher replacement levels.
- In this paper our attempt has been made to study the effect of metakaolin on strength properties of concrete considering a constant water-cementitious material ratio of 0.43 for m-35 grade concrete mix. The optimum percentage replacement of metakaolin ranging from 8 to 12% to obtain maximum 28-days compressive strength of concrete.

B. Ggbs

- Soil treated with 20% of GGBS gives the optimum strength when compared with the virgin soil with an increment of 73.79% for 21 days of curing.
- It Shows that the compressive strength of cement mortar increases as the replacement level of ggbs increases & Use of GGBS upto 75% can be recommended
- The replacement levels in the concrete studied varied from 10% to 80% and the strength efficiencies at the 28days were calculated. Strength efficiency factor varied from 1.29 to 0.70 for percentage replacement levels varying from 10% to 80%.
- Similar to FA, as the proportion of GGBS is increased; the heat of hydration is reduced.
- GGBS slowly reacts with water as compared to Portland cement, therefore stiffening/setting time of concrete is high which in turn will reduce the probability of thermal cracking
- Leaching studies revealed that GGBS does not leach heavy metals like Pb, Zn, Cr, Ni, Mo etc and also indicates that the leaching of heavy metals was well below the toxicity

limits even under aggressive conditions.

C. Metakaolin With Ggbs

- The experimental results show that GGBS and MK have positive impact on pore refinement and ITZ enhancement of concrete.
- The development of the compressive strength and durability is closely related to the evolution of the pore structure and ITZ. (Eguchi, 2011).
- Thermodynamic stability analysis indicates that silicon, as the major component of GGBS and MK, influences the stability of hydrate phases according to changes in Gibbs free energy of reaction.
- However, concrete with both Metakaolin and GGBS have not been studied under actual environment. Already, long term durability of concrete made with Metakaolin and GGBS under marine environment has been investigated.
- Heat of hydration decreases with the use of microfiller mineral admixtures.
- It help to maintain the workability and sometimes increase the workability.

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