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A Review on the Effect of Pozzolanic Properties of Metakaolin in Concrete

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ABSTRACT

This literaturepresents an overview of the pervious works carried out on the effect of replacing Metakaolin in concrete. 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. Carbon dioxide emission associated with cement manufacture have brought about pressures to reduce cement consumption through the use of supplementary materials.The recent developments in technology has shown the use of alternate additives having cementitious properties in cement as flyash, silica fume, metakaolin, blast furnace slag etc. If kaolin isthermally activated, it converts to a pozzolan material named metakaolin (MK).MK was used to improve the properties of paste, mortar and concrete. to improve their properties. The results indicate that the maximum strength of mortar occurs at around 20% MK. Compressive strengthstarts to reduce when MK goes beyond 30%MK as cement replacement. And also the results also indicated someimprovements in the cementing and mechanical properties of cement and durability of concrete.

KEYWORDS - Pozzolanic Materials, Ordinary Portland Cement, Metakaolin, Mechanical Properties, Compressive Strength, Flexural Strength andDurability.

11ntroduction

Many countries of the world are faced with inadequate provision of physical infrastructure; shelter and related amenities, which are typical factors of under development that need to be addressed through provision of alternative, cheap and affordable materials. In these areas, development requires the use of cement and other related materials such as coarse aggregate. Cement is the most widely used construction material throughout the world. This leads to an enormous production of cement to meet the increasing demand for housing and infrastructure. Cement production is however harmful on the environment due to carbon dioxide emission. Reducing cement production while maintaining sustainable development has been an important issue in the development of construction materials.The cost of cement used in concrete works is on the increase and unaffordable, yet the need for housing and other constructions requiring this material keeps growing with increasing population, thus the need to find alternative binding materials that can be used solely or in partial replacement of cement. Besides the exorbitant cost of cement, the activities of cement producing companies have depleted the natural environment and huge amount of poisonous gasses such as CO_2 and NO_2 are released into the atmosphere causing environmental pollution. These gasses are also responsible for the depletion of the ozone layer which is responsible for global warming (Shalini et al., 2006). The use of wastes material as basic raw material in concrete production may provide foreseeable solution to the challenges

2.0 Literature review

Pozzolan is defined as a siliceous or alumino-siliceous material that, in finely divided form and in the presence of moisture, chemically reacts at ordinary room temperature with calcium hydroxide, released by the hydration of Portland cement, to form compounds possessing cementitious properties (Canadian Standard Association, 2000).

Metakaolin is obtained by calcinations of pure or refined kaolintic clay at a temperature between 650 to 850°C, followed by grinding to achieve a fineness of 700 to 900m2/kg (Mohammed, 2017). Metakaolin is obtained by calcination of pure or refined kaolintic clay at a temperature between 650°C and 850°C followed by grinding to achieve a fineness of 7000 to 9000 m2/ kg with resulting material has high pozzolonicity (Nadeem et al., 2015). Kaolin is one of the industrial minerals that can be found in commercial quantities in Nigeria. It was estimated by Raw Material Research Council of Nigeria (RMRDC, 2008) that the country has a reserve of about (3) three billion metric tonnes of kaolin deposit scattered in difference parts of the country which includes Ogun, Edo, Plateau, Nassarawa, Katsina, Ekiti, Kogi, Abia, Kano, Niger, Bauchi, Sokoto, Kaduna, Oyo, Delta, and Borno states. The market for kaolin is large, sustainable and expanding because of the numerous applications of its products. Good prospects exist in kaolin mining and prospecting in Nigeria (RMRDC, 2008)

Narmatha (2020) reported that Metakaolin is a relatively new material in the concrete industry and it is effective in increasing strength, reducing sulphate attack and also improving air-void network. Pozzolanic reactions change the microstructure of concrete and chemistry of hydration products by consuming the released calcium hydroxide (CH) and production of additional calcium silicate hydrate (C-S-H), resulting in an increased strength and reduced porosity and therefore improved durability.

Egwuonwu (2019)examines the cementitious efficiency of Metakaolin, a supplementary cementitious material (SCM) in high strength concrete production. The mix design was carried out using the Absolute Volume method. The metakaolin was used to replace cement at 2.5%, 5%, 7.5% and 10% at various water/cementitious ratios of 0.20, 0.25, 0.30 and 0.35. The control mix was designed to establish a comparative basis between the mixture blended with Mk and ordinary cement concrete for all mixes. The superplasticizer was also kept constant in all mixes. Water-cementitious ratio and curing ages and the response variables (compressive strengths). The results indicated that the mix design adopted was appropriate for the production of HSC of compressive strength 95.33Mpa.

V. K. Jadoun and A. Prakash (2020) presented results of an experimental program to determine mechanical propertiesof concrete with metakaoline and marble dust replaced with cement with the knownpercentages such as 0%, 5%+5%, 7.5%+7.5%, 10%+10%, 12.5%+12.5%, 15%+15% for the grade of M30. The compressive strength of concrete is more at 10%+10% replacement of metakaoline and marble dust. The result shows that Cylinder strength of concrete is more at 10%+10% replacement of metakaoline and marble dust, workability of concrete is also reducing due o increase in percentage of metakaoline and marble dust and strength and durability of concrete increased.

Ubojiekere et al. (2018) investigated the effects of Metakaolin on the fresh state and compressive strength of high strength self-compacting concrete. The particle parking model (PPM) was adopted for the mix design of concrete constituents. The prime rationale was to eliminate the void in the self-compacting concrete (SCC). Metakaolin was used to replace cement at three incorporation ratios of 5%, 10%, and 15% at varying water to cementitious ratios of 0.25, 0.30, 0.35, and 0.40. Mixes were designed to achieve both self-compatibility and high compressive strength. Several workability tests such as slump flow, L- box, V-funnel, and J-ring were carried out. The compressive strength was measured at 7, 14, and 28 days of wet curing. The results showed that the mix design method was adequate to the proportion of SCC mixtures containing cement and Metakaolin. All fresh state properties satisfied EFNARC criteria (EFNARC, 2005). The highest compressive strength of 69.6 MPa was obtained for concrete using Metakaolin. For all mixtures, Metakaolin increased compressive strength appreciably. A similar trend was observed in all the concrete mixes, and there was a progressive increase in compressive strength as the metakaolin inclusion level increased.

Akinyele et al., (2017) investigated the use of metakaolin from the Isan-Ekiti deposit in Ekiti state, Nigeria. Chemical, slump and mechanical tests were conducted on the calcinated kaolin that gave the metakaolin. The chemical result showed that the metakaolin has pozzolanic characteristics and is classified as class “N” pozzolan. The mechanical tests revealed that cement can be partially replaced in concrete with metakaolin for up to 20% by weight.

Mohammed (2017) Presented investigation on replacement of cement with recent new pozzolonic material of Metakaolin. The compressive strength of the mix M20 i.e. without mixing of Metakaolin is 23.407N/mm2 for 28 days respectively. In the investigation the Metakaolin was used as replacement to cement up to a maximum of 17.5%. When Metakaolin is used as admixture in different percentages, the strength increased. For e.g., with 7.5% replacement of cement by Metakaolin the compressive strength at 28 days is 47.11 N/mm2 and there is an increase of compression strength by 8.53%. Considering 10% replacement, the compressive strength is 51.259 N/mm^2 there is an increase in compressive strength by 15.3%. With 17.5% replacement, the compressive strength is 42.222N/mm^2 and the decrease in compressive strength by 2.8%. From the results, it was clear that there is no advantage in using Metakaolin beyond 10%. Hence, 10% Metakaolin was taken as the optimum dosage, which can be mixed as a partial replacement to cement for giving maximum possible compressive strength at any stage.

Hamdy et al. (2017) carried out an experimental investigation on high-strength concrete's mechanical behavior made with high percentages of Metakaolin and hybrid fibers with volume fractions of 0.25% and 0.5%. A total of 315 standard test specimens (189 cubes and 126 cylinders) were cast and divided into three groups. Each group consisted of 105 specimens, and each data was based on the average results of 3 test specimens. The Metakaolin (MK) percentage was fixed in all groups (10%, 15%, 20%, 30%, 40%, and 50%) as a percentage of cement weight. Results revealed that High Strength Concrete (HSC) could be produced with a high volume of Metakaolin. The combined effect of hybrid fiber and Metakaolin showed that MK's optimum dose is 15% at all testing ages. Besides, there was a significant gain in split tensile strength due to Metakaolin and hybrid fiber.

Bhaskara 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.

Duna et al., (2016) presented the results of the investigation into the effect of metakaolin (MK) on the compressive strength of concretecontaining glass powder (GP). Plain mix, binary mixes (containing 10 % GP only by weight of cement) and ternary concretemixes (containing 10% GP with 5, 10, 15 and 20 % MK by weight of cement) were produced and cured for 7, 14, 28, 56 and 90days respectively. The results showed that generallycompressive strength decrease with increase in MK content and increase with prolong curing period. Glass powder concretecubes made with (5-20) % MK and cured for 56 and 90 days, achieved the 28 days target strength of 25 N/mm2. The optimumreplacement level was observed at G10%M15% cured for 90 days. The data obtained were subjected to regression analysis andanalysis of variance (ANOVA) in the MINITAB 16 statistical software. The model developed to predict compressive strength withcuring period and MK as predictors was highly significant at 5% level, implying there is no significant difference between thepredicted and the experimental values. The coefficients of determination, R^2 of 90.44% for the model is reasonably high,indicating a good correlation between the response and the predictor variables.

Hossam et al. (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. 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 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.

Jun et al. (2016) investigated High-Porosity Cement Foams (HPCF) properties based on ternary Portland cement-Metakaolin-Silica fume blends. The effects of ternary blends on the early-age properties of air-void structure and hardened state properties of cement foams were examined. HPCF slurries were prepared using ordinary Portland Cement, Supplementary Cementitious Materials (SCMs), accelerating agents, superplasticizers (SP), foam agents, and water. Results showed that Metakaolin (MK) and silica fume contributed to stabilizing the air-void structure due to their high pozzolanic activity.

Narmatha (2016) conducted a study on "Meta kaolin, The Best Material for Replacement of Cement in Concrete". The study investigated 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.

Ayman et al. (2015) studied the effect of applying scrap tires in high-strength concrete. Both mechanical and dynamical properties were measured. Two sets of rubberized concrete mixtures were designed and used. The variable slump was used to test the properties of concrete having 0%, 5%, 10%, 15%, 20%, and 30% volume of shredded rubber replacing fine aggregate (sand). The other set was designed to investigate the workability due to variable superplasticizer dosage. Results revealed that compressive strength reduced as the incorporation ratio of rubber increases. It was also observed that at 15% replacement, compressive strength was not significantly affected.

An investigation by Nadeem et al., (2015) presents the results of an experimental investigation carried out to find the suitability of metakaolin and fly ash in production of concrete. The conventional concrete M25 was made using OPC 53 grade and the other mixes were prepared by replacing part of OPC with metakaolin and fly ash. The replacement metakaolin levels were 5%, 10%, 15%, 20%, 25% and fly ash for all mix 5%. To evaluate optimize ratio and mechanical properties of metakaolin based concrete and compared with conventional mix. From the optimization 20% cement replacement by metakaolin was superior than all the mixes.

Guang et al., (2015): Investigated the pozzolanic reactivity of Metakaolin and the effects of Metakaolin on mechanical properties, pore structure and hydration heat of mortars by replacement of cement with Metakaolin at 0%, 6%, 10%, and 14% by weight at a constant 0.17 w/c ratio. The experimental results show that the pozzolanic reactivity of Metakaolin is higher than that of silica fume. For mortars without steel fibers, the flexural strength decreases with the inclusion of Metakaolin, whereas 10% MK blended mortars show the highest compressive strength compared to the others. For reinforced mortars with 2% steel fibers by volume, both flexural and compressive strength are remarkably enhanced. Heat of hydration tests results show that 6% Metakaolin accelerates the cement hydration, with an advanced accelerating period starting time, and maximize the heat flow which indicates maximum temperature rise. Although 14% Metakaolin blended mortar minimizes the total heat evolved, the optimal Metakaolin content is 10% with the consideration of mechanical properties.

Kavitha et al (2015) investigated the effect of metakaolin on the fresh, micro- and macro level properties of self-compacting concrete. Cement content considered = 500 kg/m^3, while the MK was used to replace cement by 5, 10 and 15%. Fresh concrete property test performed = slump flow, V-funnel flow times, L-box. Macro level properties performed = compressive strength and split tensile strength. The micro structural changes were studied using a Scanning Electron Microscope (SEM), X-ray Diffraction Analysis (XRD) and Energy Dispersive X-ray Analysis (EDX). The fresh concrete results show that SCC mixes prepared at different Water: Cement (W: C) ratios satisfied the rheological properties. MK inclusion enhanced the macro level properties. The micro level studies indicated that micro crack width was reduced due to inclusion of MK in the control mix. The optimum replacement of MK was 10%.

Nikhil K and Ajay A.H (2015) studied the valuation of Strength of Plain Cement Concrete with Partial substitute of Cement by MK. In this study they observed replacement of cement with MK and fly ash at 0%, 5%, 10% and 15% for 7days and 28 days for M20 and M25. And these results compared with the conventional concrete. Finally, they concluded that up to 15% replacement cement with MK and fly ash strength is increasing, beyond strength was decreased. Therefore, it is always better to use 10% for good results.

Yogesh R. Suryawanshi et al. (2015) studied the Compressive Strength for the Concrete by using the Metakaolin. In their research study they investigated the effects of MK & Super plasticizer on the strength properties of M35 grade concrete. Their research program is designed to find the compressive strength of concrete by partially substituting the cement with MK in concrete production. The replacement levels of cement by MK are selected as 0%, 4%, 8%, 12%, 16% and 20% for constant water-cement ratio of 0.43. For all the mixes compressive strength is found at 3, 7, 28. Current experimental study shows that 12% substitute of cement by MK gives the higher strength. MK increases the compressive strength for the concrete more than 10%.

Sanjay N. Patilet, al (2014) investigated the use of metakaolin, having good pozolanic activity and a good material for the production of high strength concrete. A review of the literature suggested that optimal performance is achieved by replacing 7% to 15% of cement with metakaolin and when MK use is less than 10%, the benefit is not fully realized, and hence At least 10% of metakaolin should be used. After 28 days the compressive strength value of concrete with metakaolin may exceed 20%. A 15% dose of metakaolin leads to loss of function. Due to the increasing amount of perceptual ratio of metakaolin in concrete mixtures, higher doses of super plasticizers are required to ensure the duration of work.

Nazeer M et al. (2014) studied the assessment of Strength Studies on Metakaolin Blended with High-Volume Concrete. Generally, the addition of Pozzolana to concrete will improve some properties like Workability, Later age strength and Resistance to sulfate and Chloride attacks. In their research work 50% of cement was replaced with Class-F MK and 0%, 5%, 10%, 15% and 20% of Metakaolin is also replaced in place of cement for M30 grade concrete mix. From this research study they concluded as addition of MK and SF in concrete reduces the Workability. Mechanical properties for example compressive strength, split tensile strength and modulus of elasticity shows diminishing trend with the increasing of MK. The declined in workability of high-volume MK concrete changed with the addition of MK shall be expressed as a function of MK content in the mix.

Dinakar (2013) presented the effect of incorporating metakaolin on the mechanical and durability properties of high strength concrete for a constant water/binder ratio of 0.3.MK mixtures with cement replacement of 5, 10 and 15 %were designed for target strength and slump of 90 MPa and 100 ± 25 mm. From the results, it was observed that 10 % replacement level was the optimum level in terms of compressive strength. Beyond 10 %replacement levels, the strengthwas decreased but remained higher than the control mixture. Compressive strength of 106 MPa was achieved at 10 %replacement. Splitting tensile strength and elastic modulus values have also followed the same trend. In durability tests MK concretes have exhibited high resistance compared to control and the resistance increases as the MK percentage increases. The investigation revealed that the local MK has the potential to produce high strength and high performance concretes.

Nova John (2013) investigated the cement replacement levels at 5%,10%,15%,20% by weight for metakaolin. The strength of all metakaolin admixed concrete mixes over shoot the strength development of concrete. Mix with 15% metakaolin was superior to all other mixes. The increase in metakaolin content improves the compressive strength, split tensile strength and flexural strength upto 15% replacement. The result encourages the use of metakaolin, as pozzolanic material for partial cement replacement in producing high strength concrete. The inclusion of metakaolin results in faster early age strength development of concrete. The utilization of supplementary cementitious material like metakaolin concrete can compensate for environmental, technical and economic issues caused by cement production.

Rashad et al. (2013) in his paper "Metakaolin as cementitious material: History, source, 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.

Dhinakaran (2012) studied the strength increases by MK concrete is effective only at the early age of concrete and in the long term the strength increase is only marginal. The increase in compressive strength for MK concrete was greater especially at higher water cement ratios (i.e., 0.4 and 0.5) and hence more suitable for higher w/cm ratios. From the studies an optimum percentage of MK was found to be 10% for all w/cm ratios except for 0.32 and for 0.32 it was 15%. MK concrete higher increase in strength at early ages beyond 28 days it was found to be less than 10%. The maximum compressive strength of 59.25 N/mm2 was observed at 0.4 w/cm with 10% MK. Addition of MK reduced the pH values, but the reduction is insignificant, since the pH values are still above 11.5, which will be helpful for maintaining the steel in a passive state itself. The depth of penetration of chloride ions for MK concrete is much lesser than control concrete. The minimum rate of reduction of chloride penetration depth for MK admixed concrete were arrived as 78%, 38%, 25% and 25% for w/cm ratios 0.32, 0.35, 0.40 and 0.50 respectively. The maximum rate of reduction was observed as 95% for 0.32 and 0.3 ratios.

Patil (2012) studied the increase in the compressive strength of concrete with increase in High Reactivity Metakaolin content up to 7.5%. Thereafter there was slight decline in strength for 10%, 12% and 15% due excess amount of HRM which reduces the w/b ratio and delay pozzolanic activity. The higher strength in case of 7.5% addition was due to sufficient amount of HRM available to react with calcium hydroxide which accelerates hydration of cement and forms C-S-H gel. The 7.5% addition of high reactivity metakaolin in cement was the optimum percentage enhancing the compressive strength at 28 days by 7.73% when compared with the control mix specimen. The 7.5% addition of high reactivity metakaolin in cement is enhanced the resistance to chloride attack. The compressive strength of concrete incorporated with 7.5% HRM is reduced only by 3.85% as compared with the reduction of strength of control mix specimen is by 4.88%. The 7.5% addition of high reactivity metakaolin in cement was also enhanced the resistance to sulphate attack. The compressive strength of concrete incorporated with 7.5% HRM is reduced only by 6.01% as compared with the reduction of strength of control mix specimen by 9.29%.

Duna and Matawal (2007) investigated the possibility of using metakaolin to replace cement in sandcrete block production. The sandcrete blocks were produced using 5,10,20, 30, 35 and 40% metakaolin partially replacing cement. Properties such as density, shrinkage and compressive strength were determined. They reported that the compressive strength of blocks decreases with increase in metakaolin content. They recommended the use of metakaolin upto 30% replacing cement in sandcrete block production.

Table 1:Properties of Cement and Metakaolin (Narmatha, 2016)

Chemical composition	**Cement %**	**Metakaolin %**
Silica (SiO2)	34	54.3
Alumina $Al_2{}^{O}{}_3$	5.5	38.3
Calcium oxide CaO	63	0.39
Ferric oxide Calcium oxide (Fe_2O_3)	4.4	4.28
Magnesium oxide (MgO)	1.26	0.08

Potassium oxide (K_2O)	0.48	0.50
Sulphuric anhydride (SO_4)	1.92	0.22
LOI	1.3	0.68
Specific gravity	3.15	2.5
Physical Form	Fine Powder	Powder
Colour	Grey	Off white

3.0 CONCLUSION

From the studies conducted, several percentages of replacement are done to investigate the mechanical properties of modified concrete with control mix.

(1) The Metakaolin content increases the compressive strength, split tensile strength and flexural strength gets increased. 10%- 20% Metakaolin was taken as the optimum dosage, which can be utilized by using super plasticizer. Mixed as a partial replacement to cement for giving maximum possible compressive strength at any stage.

(2) Most of authors believed that MK reduced the workability the setting time slightly increased with increasingMK content, but this mainly depended on cementcontent, chemical admixture dosage and its content,MK content and its fineness

(3) The optimum replacement level of the blended Metakaolin-Glass concrete was obtained at G10% M15% and cured for 90 days.The optimum recorded highest strength increase of compressive strength over the control sample whencompared to other cement replacement levels.

(4) As far as the durability properties are concerned. Metakaolin found to reduce water permeability, absorption and chloride permeability as the replacement percentage increases. This may be due to the filler effect of Metakaolin particles which has substantially reduced thepermeability or porosity of the concrete.

(5) The utilization of supplementary cementitious material like Metakaolin in concrete can compensate for environmental, technical and economic issues caused by cement production.

Reference

Akinyele, J.O.; Odunfa, S.O., Famoye, A.A. and Kuye, S.I (2017) Assessment of Isan-Ekiti Metakaolin as a Pozzolan in Concrete Centre for Research and Development (CERAD). JoST. 2017. 8(2): 26-35.

Ayman, M., & Mohamed, A. E., Mechanical Properties of High Strength Concrete with Scrap Tire Rubber. Journal of Construction and Building Materials, 93, (2015),249-256.

Canadian Standards Association, CAN/CSA A3000-98,'Cementitious Materials Compendium‖, 2000, 193. Compos. 32 (2); 212-127.

Dhinakaran (2012). Compressive strength and chloride resistance of Metakaolin Concrete. Journal of Civil Engineering, Vol. 16 (7), pp 1209-1217.

Dinakar P, Pradosh K. Sahoo, and Sriram G (2013): Effect of Metakaolin Content on the Properties of High Strength Concrete International Journal of Concrete Structures and Materials Vol.7, No.3, pp.215–223, September 2013 DOI 10.1007/s40069-013-0045-0 ISSN 1976-0485 / eISSN 2234-1315

Duna S. and Matawal D.S. (2007). Properties of Hollow Sandcrete Blocks Using Metakaolin as Partial Replacement of Cement. Journal of Environmental Sciences 11(1). 106-116

Duna Samson, Musa Abdullahi, Mohammed Abba-Gana (2016). EFFECT OF METAKAOLIN ON COMPRESSIVE STRENGTH OF CONCRETE CONTAINING GLASS POWDER. International Journal of Research in Engineering and Technology. Volume: 05 Issue:12

Egwuonwu, William, C., Iboroma, Z.S Akobo., Barisua and E. Ngekpe. (2019).Effect of Metakaolin as a Partial Replacement for Cement on the Compressive Strength of High Strength Concrete at Varying Water/Binder Ratios. SSRG International Journal of Civil Engineering Volume 6 Issue 1, 1-6

Guang Jiang (2015)"Effects of metakaolin on mechanical properties, pore structureand hydration heat of mortals at 0.17 w/b ratio. Construction and building materials 93:564-572

Hamdy, K., Shehab. E., Ahmed, S., Eisa, B. H., Abdel, A., & Ahmed,I.,(2017): Mechanical Performance of High Strength Concrete Made from High Volume of Metakaolin and Hybrid Fibers. Journal of Construction and Building Materials.,140,pp 203-209.

Hossam S, Hassan A. (2016) Time-dependence of chloride diffusion for concrete containing metakaolin, Building Engineering, Vol 7, Pp 159-169.

Jun, J., Zhongyuan, L., Yun, H. N., Jun, L., & Yu, P. Z.,(2016). Investigation of the Properties of High-Porosity Cement Foams Based on Ternary Portland Cement-Metakaolin-Silica Fume Blends. Journals of Construction and Building Materials. 107, (2016),181-190.

Kavitha O.R (2015)" Fresh, micro- and macrolevel studies of metakaolin blended self-compacting concrete", Applied Clay Science 114 (2015).

M Mohammed Ashik and Gomathi D (2017): Strength Properties of Concrete Using Metakaolin. International Journal of Engineering Research & Technology (IJERT) http://www.ijert.org ISSN: 2278-0181 IJERTV6IS110063 Published by : www.ijert.org Vol. 6 Issue 11, November – 2017.

Nadeem Pasha, Mahammad Meharaj, Anil Kumar Mashyal, Vedawrata and Banasode (2015). An Experimental Study on Strength Characteristics of Concrete by using Fly Ash and Metakaolin as Partial Replacement of Cement. IJSRD - International Journal for Scientific Research &

Development| Vol. 3, Issue 02, 2015 | ISSN (online): 2321-0613

Narmatha and Felixkala (2016): Metakaolin, the best material for replacement of cement in concrete. international journal of advanced research ·July 2016 doi: 10.21474/ijar01/1054

Nazeer M. and Kumar R.Arun (2014). Strength Studies on Metakaolin Blended High-Volume Fly Ash Concrete. International Journal of Engineering and Advanced Technology (IJEAT). ISSN:2249-8958, Volume 3 Issue 6.

Nikhil K and Ajay A. (2015): Evaluation of Strength of Plain Cement Concrete with Partial Replacement of Cement by Meta Kaolin & Fly Ash. International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181. IJERTV4IS050860 www.ijert.org Vol. 4 Issue 05, May-2015

Nova John (2013). Strength properties of metakaolin admixed concrete. International Journal of Scientific and Research Publications, volume 3, issue 6, pp 1-7

Patil (2012), Strength and Durability of High Performance Concrete Incorporating High Reactive Metakaolin, International Journal of Engineering Research. vol.2 (3), pp 1099 -1104.

Rashad A M. (2013) Metakaolin as cementitious material: History, scours, production and composition –A comprehensive overview, Construction and Building Materials , Vol 41, Pp 303-318

Rashad A M. (2013) Metakaolin as cementitious material: History, scours, production and composition –A comprehensive overview, Construction and Building Materials, Vol 41, Pp 303-318

Raw Materials Research and Development Council (RMRDC) (2008), Technical Brief on Minerals in Nigeria; (Kaolin) Nov. pp 6-21

Sanjay N. Patilet.al (2014): Metakaolin- Pozzolanic Material for Cement in High Strength Concrete. (IOSR-JMCE) ISSN: 2278- 1684, PP: 46-4.

Shalini, A. Prem,V. and Dahiya, R. P. (2006). Application of a System Dynamics Approach for Assessment and Mitigation of CO2 Emissions From Cement Industry. Journal of Environmental Management, 79:383-398.

Ubojiekere, E.O, Barisua, E.N, Godfrey, W.G.J, Chimene, O., Workability and Mechanical Properties of High-strength Self-Compacting Concrete blended with Metakaolin. International Journal of Civil Engineering., 5, (2018),2348 – 8352.

V. K. Jadoun and A. Prakash (2020) Strength and Durability Properties of Concrete with PartialReplacement of Cement with Metakaolin and Marble Dust. Journal of Interdisciplinary Cycle Research, Volume 12 issue7.

Yogesh R., Suryawanshi, Sandeep G. Patil, Yogesh S. Tate, Onka R. Ukarde, Amit H. Kadam (2015) Compressive strength on concrete. International Journal of Engineering Research, IJOER. Vol.3. pp 49-54