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CHARACTERISTICS BEHAVIOR OF PARTIALLY REPLACED CEMENT WITH KANKARA METAKAOLIN IN CONCRETE PRODUCTION

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ABSTRACT

Cement which is the basic constituent of concrete is posing a global threat through its adverse effects on environment during its production processes. It has become very popular that in the production of 1ton of cement, 1ton of CO_2 is released into the atmosphere which causes greenhouse emission and global warming through. It has therefore become imminent to have alternative materials that will be readily available, ecofriendly and not to compromised strength and with required durability to replace conventional cement. In this research work, calcined kaolin obtained from Kankara Local Government of Katsina State was used to replace cement at 5%, 10%, 15%, 20% and 25% respectively. Oxide composition test, slump test, compressive strength test and Split Tensile strength test were carried out for both control and concrete produced with metakaolin as partial replacement of cement. It was noticed that the metakaolin was of class N Pozzolan and having a good compressive and tensile strengths that surpassed that of the control concrete mix. From test results it was concluded that cement can be replaced by metakaolin at 20% replacement to achieve a sustainable concrete with good strength and durability. One of the setbacks that was noticed is that the percentage increase of metakaolin in the concrete decrease the workability of the concrete and has to be compensated by adding super plasticizer. Also, even though kaolin is available in some parts of the country, the proximity and manner to which it is locally processed by the communities in large quantity need to be worked on for it commercialization and effective usage.

Keywords: Cement, calcined kaolin, metakaolin

INTRODUCTION

The persistent increase in the population of human beings globally is undoubtedly leading to an increasing demand for more houses for shelter. Cement which is widely recognized as the major constituent in building construction is posing a serious challenge to the entire globe. However, the production of cement (a major part of concrete) consumes large amounts of energy and this leads to the release of large amounts of carbon dioxide "CO_2" and other greenhouse gases "GHGs" to the environment. It was revealed that production of one ton of cement generates about one ton of CO_2 and other GHGs. Consequently, the environmental issues related to cement production brought the idea of sustainable development in the construction industry. Researchers in the building construction industries are interested to having sustainable alternative materials that will be ecofriendly, less costly and with effective and efficient replacement properties of cement without compromising strength and durability properties (Joseph, 1984; emundla & Konoki, 2020). Metakaolin is one of the readily available natural resources which can replace Ordinary Portland Cement (OPC). Metakaolin is a Pozzolanic material that is produced from the calcination of pure refined kaolinite clay at a temperature between 650^{o}C and 850^{o}C (Narmatha & Felixkala, 2016).

Raw Material Research Council of Nigeria (RMRDC) in 2008, estimated the commercial quantities of Kaolin (Industrial Mineral) deposit in Nigeria to be about three (3) billion metric tonnes scattered across Katsina, Niger, Bauchi, Ogun, Ekiti, Oyo, Abia, Kano, Kogi, Kaduna, Nasarawa, Sokoto, Borno, Edo, Plateau and Delta States ((RMRDC), 2008). In the assessment of Isan-Ekiti Metakaolin by Akinyele et al. (2017) as a Pozzolan in concrete it was observed that cement can be replaced in concrete with up to 20% Metakaolin without reducing the strength and durability properties of the concrete.

Jamal et al. (2018), in their work on Metakaolin, observed that Pozzolanic materials such as calcined clay are not either waste or industrial byproducts and requires energy to be produced but the energy required for their production is far less than that used in the production of cements.

Dinakar et al. (2013), in the Effect of Metakaolin Content on the Properties of High Strength Concrete, stated that local Metakaolin was found to reduced water permeability, absorption and chloride permeability as the replacement percentage of Cement with Metakaolin increases.

EXPERIMENTAL PROCEDURE

Materials

Cement: Ordinary Portland Cement (OPC) conforming to BS EN 197-1-2010 of Dangote brand is used throughout the investigation for the production of the standard control and that of partial replacement of cement in the concrete. Specific gravity of the cement was found as 3.14.

Coarse Aggregate: The coarse aggregate used for this research is crushed broken hard granite chips with maximum size of 20 mm and with specific gravity of 2.62, grading confirming to BS EN 12620-2013.

Fine Aggregate: Natural sharp sand with particle size distribution conforming to ASTM C33 was used for the investigation. The siliceous sand has a specific gravity of 2.50.

Metakaolin: Kaolin samples used throughout this research study were collected from Dan-Marke in Kankara, Kankara Local Government Area of Katsina State, Nigeria. The Kaolin was fired (Calcinated) to a temperature between 650^{0}C and 850^{0}C, at National Cereal Research Institute (NCRI) Baddeggi, Niger State to form Metakaolin. The calcination was based on the recommendation of ASTMC 618-12, (2008). The chemical and mineralogical analysis tests on Kaolin and the Metakaolin were carried out at Chemical

Science Department of Ahmadu Bello University Zaria and represented in Table 1.

Water: Potable water was obtained from Federal Polytechnic Bida, Niger State, Nigeria that conforms to NIS 554: 2007 was used for the investigation.

Methods

Mix Proportion: After obtaining the Chemical Composition of the Binders, the materials were set for concrete production. The binders (Metakaolin and/or Cement), aggregates and water were mixed using 0.4 water-binder ratio (w/b) until a homogeneous paste was achieved. The mixing process was continued for up to 10 minutes for all mixes of 0%, 5%, 10%, 15%, 20% and 25% replacement of cement with Metakaolin with a trial mix of 20 MPa strength at 28 days. The total mass of fine and coarse materials used was maintained throughout for the pastes/concretes, while Cement and Metakaolin varies and when summed up gives 100% by mass. The pastes/concretes casted on each percentage replacement for slump test using a frustum cone mould having top diameter of 100mm and bottom diameter of 200 mm in according to BS.1881-2: (1996). The pastes/concretes were also casted in cube mould of kept in room temperature, demoulded after 24 hours and cured in a big open tank containing clean and pure water at room temperature of 23±2 °C for required numbers days (7 days, 14 days and 28 days) for crushing using Compressive Testing Machine in according to BS EN 12390-3 (2009). Another 36 cylindrical concrete cubes were casted for Tensile Strength Test in according to BS EN. 12390-6 (2009), the cylinder having a diameter of 150 mm and 300 mm length was used. Grade 20 concrete with 0.4 water-binder ratio having same percentage of metakaolin replacement and curing ages of 28 days and 90 days was adopted. The Tensile Strength was determined using the equation (1). Results for the Mix Proportion and Slump, Compressive Strength and Tensile Strength tests were given in Tables 2, 3 and 4 respectively while the tests were designated as S_0, S_5, S_{10}, S_{15}, S_{20} and S_{25} for Slump, C_0, C_5, C_{10}, C_{15}, C_{20}, and C_{25} for Compressive and T_0, T_5, T_{10}, T_{15}, T_{20} and T_{25} for Split Tensile Strength.

$$T = \frac{2P}{\pi dl} \qquad (1)$$

Where; T is the Tensile Strength in N/mm^2, 'P' is the failure Load in kN, 'd' is the diameter of cylinder and 'l' is the length of cylinder.

RESULTS AND DISCUSSION

Chemical Content of Metakaolin

The analysis of the Oxide composition of the Metakaolin showed that the percentage component of the Oxides present in the Metakaolin is more than 70% and therefore revealed it is Pozzolanic material based on ASTM C618-84. From Table 1, it was observed that the combination of SiO_2 + Al_2O_3 + Fe_2O_3 is equal to 95.36%, this is greater than 70% recommended by the code for Pozzolans. Thus, the metakaolin is classified as class "N" Pozzolan. This showed that metakaolin obtained from kaolin clay gotten from Kankara Local Government of Katsina State and used in this work is a pozzolanic material and can be used as supplementary material for cement replacement in concrete production.

Table 1: Chemical Content of OPC, Kaolin and Metakaolin (% by Mass)

Oxides	OPC	Kaolin	Metakaolin
CaO	63.8	0.958	0.24
SiO_2	21.4	56.026	53.83
Al_2O_3	5.1	38.788	40.06
Fe_2O_3	2.6	1.017	1.47
Na_2O	0.14	0.057	0.06
MgO	0.36	0.053	0.12
K_2O	1.88	2.062	0.16
SO_3	3.38	0.224	-
L.O.I	-	0.34	1.56
Specific Gravity	3.14	2.33	2.45
Physical Form	Fine Powder	Granular	Powder
Colour	Grey	White	Off white

Mix Proportion and Slump Test Result

From the Concrete Mix Proportion and Slump test in Table 2, homogenous plastic concrete of Grade M20 strength was achieved using 0.4 water – binders ratio. The workability for the mixture decreases as the percentage replacement of the metakaolin increases. The increasing addition of metakaolin in replacing cement, lowered the concrete workability, this is attributed to the large surface area of the Metakaolin. The slump value for the control mix was 88 mm and as the replacement with metakaolin continued, the slump value decreases from 78 mm to 61 mm for S_5 and S_{25} Samples respectively. Meaning the percentage replacement of cement with metakaolin has a raise in the percentage from 11.36% to 30.68% slump of Metakaolin to Control. This therefore indicates Super plasticizer is needed to achieving adequate concrete workability.

Table 2: Mix Proportion and Concrete Slum Test

Ingredients	OPC (0%MK)	5%MK	10%MK	15%MK	20%MK	25%MK
Cement (g)	520	495	470	445	420	395
Metakaolin (g)	0	25	50	75	100	125
Fine Aggregate (g)	795	795	795	795	795	795
Coarse Agg. (g)	984	984	984	984	984	984
Water (g)	165	165	165	165	165	165

Specimen	Slump Height H1 (mm)	Test I (mm)	Test II (mm)	Test III (mm)	Average Slump H2 (mm)	Slump Value (H1-H2) mm
S0	300	209	212	215	212	88
S5	300	220	222	225	222	78
S10	300	228	231	229	229	71
S15	300	232	230	233	232	68
S20	300	234	234	236	235	65
S25	300	240	238	239	239	61

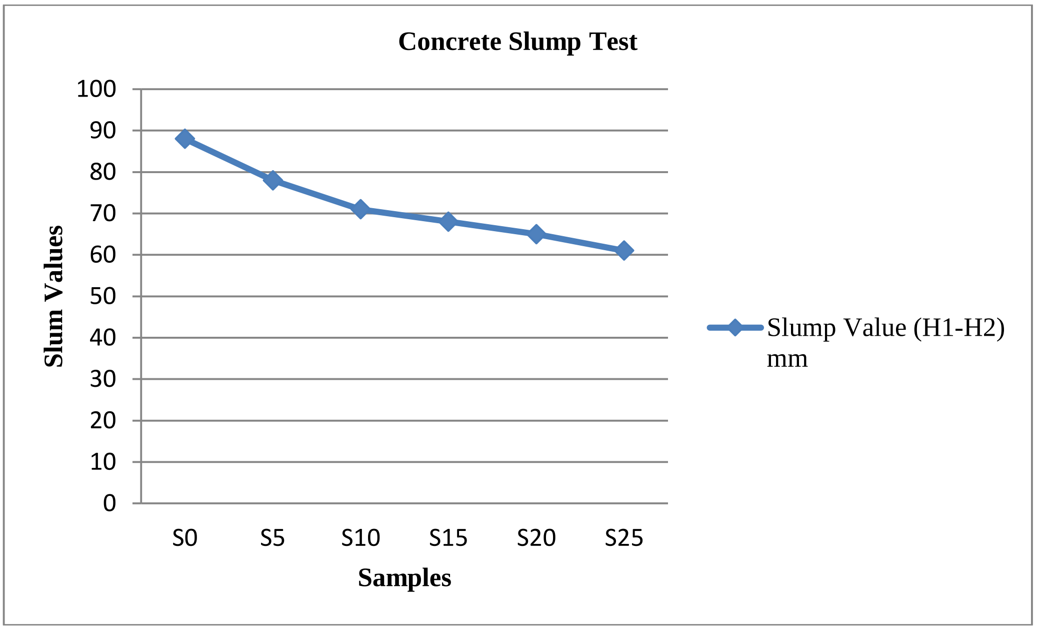

Figure 1. Variation of Concrete Slump Values.

Compressive Strength Result
From the Compressive strength results for both Control and Concrete produced in percentage replacement of Cement with Metakaolin as presented in Table 3 shows that, the 7 days compressive strength varied between 15 N/mm^2 and 18 N/mm^2. The 14 days Compressive Strength varied between 16 N/mm^2 and 18 N/mm^2. And the 28 days compressive strength varied between 20 N/mm^2 and 22 N/mm^2. The 20 % percentage replacement of cement with metakaolin exhibited the highest strength value. All concretes including the control attained the target strength of 20 N/mm^2 in 28 days. The concrete compressive strengths begin to fall at 25% Cement replacement of metakaolin for 7 days, 14 days and 28 days. However, at 28 days the percentage increase with respect to control at 5%, 10%, 15%, 20% and 25% replacement with metakaolin are 1.66%, 3.90 %, 6.33%, 7.99% and 6.33% respectively. In this case, the best proportion for the mix is 20 % replacement which gave a substantial increase in strength.

Table 3: Compressive Strength in N/mm^2

Test Ages	OPC (0%MK) (C_0)			5% MK (C_5)			10%MK (C_{10})			15%MK (C_{15})			20%MK (C_{20})			25%MK (C_{25})		
7days	15.3	16.5	15.6	16.1	16.6	17.2	17.0	17.1	16.9	16.7	17.6	17.1	17.4	17.5	17.8	17.3	17.1	17.2
		15.80			**16.63**			**17.00**			**17.13**			**17.57**			**17.20**	
14days	17.1	16.2	16.5	16.7	17.4	17.1	17.1	17.3	17.4	17.4	17.1	17.7	17.7	17.4	17.9	17.6	17.4	17.4
		16.60			**17.07**			**17.27**			**17.40**			**17.67**			**17.47**	
28days	19.8	21.4	20.4	19.9	20.8	21.9	20.2	21.4	22.4	21.0	21.9	22.6	21.8	22.7	22.0	21.8	21.8	21.9
		20.53			**20.87**			**21.33**			**21.83**			**22.17**			**21.83**	
% of Increasing from 0%MK		**-**			**1.66%**			**3.90%**			**6.33%**			**7.99%**			**6.33%**	

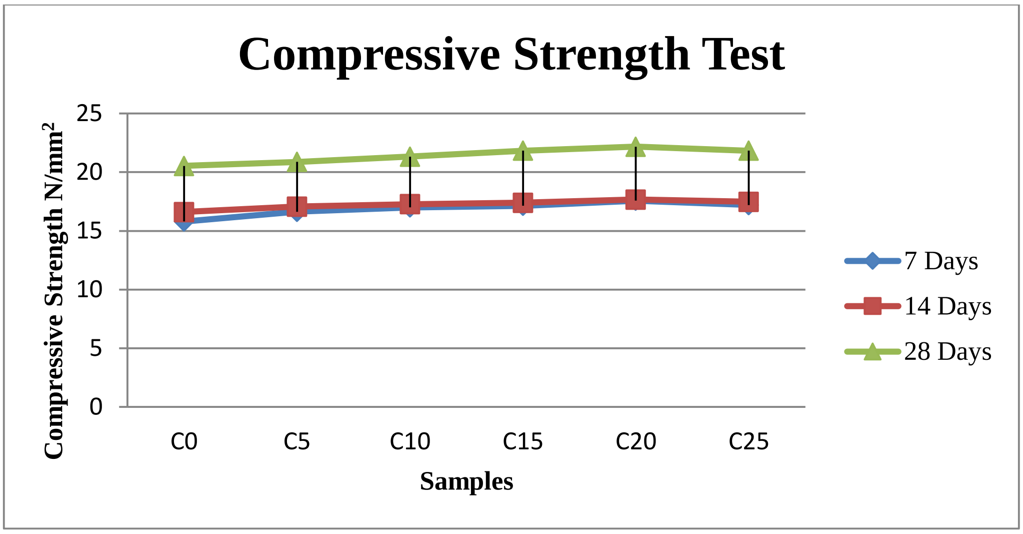

Figure 2. Variation of Concrete Compressive Strength Values.

Split Tensile Strength Test Result

Like the compressive strength result, the split tensile strength values also increases as the percentage replacement of the cement with metakaolin increases with 20% replacement having the highest strength value of 2.87 N/mm^2 and 3.77 N/mm^2 for the 28 days and 90 days respectively. While at 25% replacement the strengths begin to fall indicating 20% replacement as the best proportion for the mix.

Table 4: Split Tensile Strength in N/mm^2

Test Ages	OPC (0%MK) (T_0)			5% MK (T_5)			10% MK (T_{10})			15% MK (T_{15})			20% MK (T_{20})			25% MK (T_{25})		
28days Strength	2.1	2.2	2.2	2.3	2.3	2.5	2.6	2.2	2.4	2.7	2.5	2.6	2.8	2.9	2.9	2.6	2.5	2.4
		2.17			2.37			2.40			2.60			2.87			2.50	
90days Strength	3.2	3.3	3.2	3.3	3.4	3.5	3.6	3.4	3.6	3.5	3.7	3.8	3.8	3.7	3.8	3.5	3.6	3.6
		3.23			3.40			3.53			3.67			3.77			3.57	
% of Increasing from 0%MK		-			5.26%			9.29%			13.62%			16.72%			10.53%	

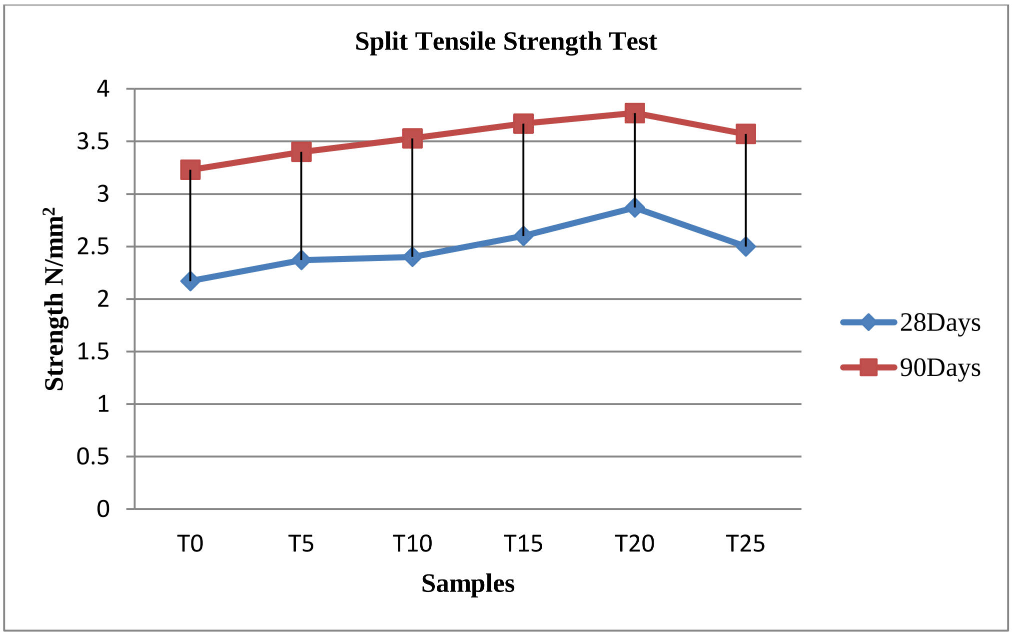

Figure 4. Variation of Concrete Split Tensile Strength Values.

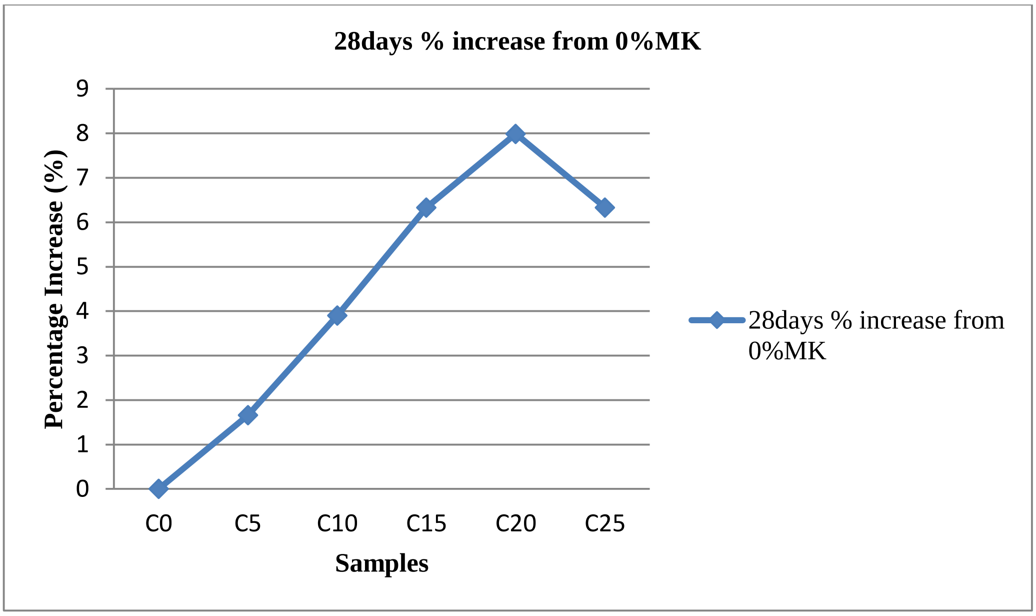

Figure 3. Variation of Concrete Compressive Strength of 28days % Increase from 0% Metakaolin.

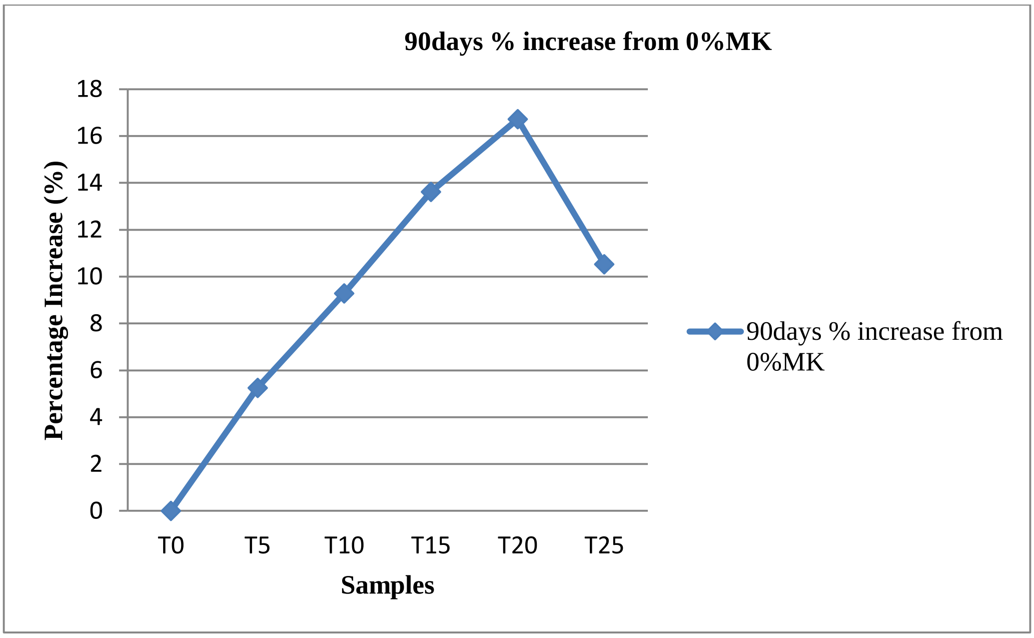

Figure 3. Variation of Concrete Tensile Strength of 90days % Increase from 0% Metakaolin.

Discussion

The experimental results shows that there was an increased in the overall strength (split tensile strength and compressive strength) of concrete with an increase in the percentage of metakaolin up to 20% cement replacement with metakaolin and after that, the 25% metakaolin replacement shows a gradual declined in the overall strength. That is further increase in the amount or percentage of metakaolin above 20% replacement caused reduction in strengths. Comparing with other research findings (Malagavelli et al, 2018 and Kaur et al, 2016) in which they suggest 10% and 9% replacement of cement with metakaolin respectively, there is a significant improvement in percentage replacement with respect to the previous findings from the researchers. Therefore for a better strength gain the optimized percentage replacement can be obtained up to 20% replacement of cement with metakaolin.

CONCLUSION

The present research carried out focused on the characteristics behavior of concrete produced with partial replacement of cement with metakaolin and based on the experimental findings it was concluded that, the percentage increase of metakaolin in the concrete leads to decrease in the workability of the concrete and has to be compensated by adding Super plasticizer, both compressive and tensile strengths for all the concrete produced with Metakaolin over shoot that of ordinary Portland Cement, 20% cement replacement with Metakaolin is superior to all other mix proportions and finally the result encourages the use of metakaolin as a local material to replacing cement of about 20% by mass in the production of cement.

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