Flexural Behavior of High Strength Reinforced Concrete Beam with Metakaoline as Partial Replacement for Cement

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Abstracts: Concrete is one of the most common materials used in the construction industry. In the past few years, many researchers have study and modification has been done to produce concrete which has the desired characteristics. There is always a search for concrete with higher strength and durability. In this matter, blended cement concrete has been introduced to suit the current requirements. Cementitious materials known as pozzolans are used as concrete constituents, in addition to Portland cement. Originally the term pozzolan was associated with naturally formed volcanic ashes and calcined earths will react with lime at ambient temperatures in the presence of water. Recently, the term has been extended to cover all siliceous/aluminous materials which, in finely divided form and in the presence of water, will react with calcium hydroxide to form compounds that possess cementitious properties. The current area of research in the concrete is introducing clay (metakaolin) in the concrete.

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1. Introduction

The study of High Strength Concrete has become interesting, with the tendency of concrete building structure becoming taller and larger. However, over many years of gradual development, the production of high strength concrete is now economically and technically practicable. It has become popular around the world with its increased use in structural applications (Crozier and Sanjayan, 2000).

Due to its many advantages over normal strength concrete, high strength concrete has been used in bridges, columns and shear wall of high-rise buildings, offshore structures, and in construction where durability and strength is critical. High strength concrete provides a higher level performance in strength and durability compared to conventional concrete. High strength concrete allows the use of smaller size of concrete structure which increases the amount of usable space and decrease the construction cost because of its ability to carry larger loads as well as high early strength development of concrete which allows early stripping of formwork, thus speeding up concrete construction (Ding and Li, 2002).

Variety of additives such superplasticer and water reducing admixtures are easily available in the production of high strength concrete and this had increased the popularity of uses of high strength concrete in structural buildings(Phan and Carino, 2000).

Metakaolin is normally produced by calcining pure clays at appropriate temperatures. Kostuch, *et al*. (2000) demonstrated that metakaolin can also be obtained by the calcination of indigenous laterite soils. On calcination of laterites in the range 750–800°C, kaolinite and gibbsite are transformed into transition phases of metakaolin and amorphous alumina both of which possess pozzolanic properties. Ramlochan, et al (2005) showed that blended cements containing 30% calcined laterites produced strengths (between 7 and 28 days) higher than that of plain concrete pastes. At 180 days, the strength of paste containing 50% calcined laterites was 87% of that developed by plain Portland cement.

The raw material input in the manufacture of metakaolin (MK) is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain.

Metakaolin differs from other supplementary cementitious materials (SCMs), like fly ash, silica fume, and slag, in that it is not a by-product of an industrial process; it is manufactured for a specific purpose under carefully controlled conditions. Metakaolin has great potential for improving concrete durability (Poon et al 2001). Also, because the supplementary calcium-silicate-hydrate (C-SH) formed during the pozzolanic reaction with metakaolin has a lower Ca/Si ratio than ordinary calcium-silicate-hydrate (C-SH), these products bind alkali ions from the pore solution better thus reducing concrete's susceptibility to alkali-silica reaction (ASR).This potential beneficial use of metakaolin is particularly relevant, as silica fume agglomerates have been shown to contribute to alkali-silica reaction (ASR) expansion in some cases. Metakaolin has also been shown to decrease concrete permeability, which in turn increases its resistance to sulfate attack and chloride ion ingress. Additionally, metakaolin may reduce autogenous and drying shrinkage, which could otherwise lead to cracking. Thus, when used as a partial replacement for portland cement, metakaolin may improve both the mechanical properties and the durability of concrete (Sabir et al, 2001).

The aim of this study is to assess the flexural behavior of high strength reinforced concrete beam using metakaolin as a partial replacement for cement.

2. Materials and Methods

2.1 Selection of materials

The choice of ordinary Portland cement for this experiment conforms to the requirements of BS12. River sand used for this study was obtained from Majidun River in Lagos, Nigeria and is free from deleterious materials. Crushed granite was purchased from a quarry site at Lagos Ibadan expressway and Metakaolin were obtained in sufficient quantities from calcinations of clay in the laboratory to 700^{0c}.

2.2. Mix proportions and casting of concrete cubes

Batching operation by volume approach was adopted in the study. Preliminary mixes of 1:1:11/2 (cement: fines: coarse) is investigated with water/cement ratio of 0.35. The fine aggregate used was sharp sand. Two categories of samples were used, the first was cast cubes of size 150 x 150 x 150mm the second was beams of sizes 150 x 150 x 750 mm. The cast cubes were used to determine the optimum percentage cement replacement by metakaolin while the beam specimen were used to determine the flexural characteristics. The mould was assembled prior to mixing and properly lubricated for easy removal of hardened concrete cubes. Concrete cubes were prepared in percentage replacement by weight of cement to metakaolin of 0%, 5%, 10%, 15%, 20%, 25% and 30%.The mixture was properly turned within the mixing machine until it reached a plastic state which was fed into lubricated cast iron moulds. Water curing method was adopted in this paper and the specimens were made in accordance with BS 1881.

The molded concrete cubes were given 24 hours to set before demolding. They were then immersed into a large curing tank in order to increase the strength of the concrete, promote hydration, eliminate shrinkage and absorb heat of hydration until the age of test. Cubes prepared were cured for 3 days, 7 days, 28 days and 90 days. The cubes were weighed before testing and the densities of cubes at different time of testing were measured. Prior to testing, the specimens were brought out of the curing tank, left outside in the open air for about 2 hours before crushing. The compressive strengths of the cubes were tested in accordance to BS 1881 using universal testing machine also the shrinkage test. The purpose of the compressive strength test done on cubes was to obtain optimum metakaolin cement replacement

Table 1: Chemical Composition of OPC and Metakaolin (MK)

Chemical Composition	OPC (%)	MK (%)
SiO_3	20.69	51.6
Al_2O_3	4.72	41.3
Fe_2O_3	3.06	4.64
CaO	63.76	0.09
MgO	2.08	0.16
TiO_2	0	0.83
SO_3	2.92	0
K_2O	0.61	0.62
Na_2O	0.26	0.01
LOI	0.87	0

2.3. Reinforced concrete beam fabrication details

A total of 6 beams were fabricated and tested. Three set of beams(A) were made of ordinary Portland cement and the remaining three set of beams(B) had cement replaced with 15% metakaoline cement. The yield strength, (fy) for the tension steel bars were 460 N/mm^2. For Y16mm diameter bar and Sufficient shear links were also provided along the beam using Y8mm. Immediately after casting, the beams were covered with plastic sheet and moist cured for another 28 days, after which the beams were left in ambient laboratory conditions of 25 ± 3°C and 74 – 88% relative humidity until the age of test. Testing of beams was conducted at an age of about 28 to 90 days. The top surface of the beams was also instrumented with a strain gauge to measure the concrete compressive strains in the pure bending region. LVDTs (linear voltage displacement transducers) were used for measuring deflections.

The test was carried out using a 1,000 kN hydraulic actuator and the beams were subjected to three-point loads under a load control mode with 15 to 25 increments until failure. The distance between the loading points was kept constant at 700 mm. The development of cracks was observed and the crack widths were measured using a hand-held microscope with an optical magnification of X40 and a sensitivity of 0.02 mm.

3. Result and Conclusions

This chapter focuses on the results obtained from laboratory test such as slumps test, compressive cube test, flexural strength test, Load increment and ultimate load, strain reading, deflection at mid span, crack width and crack length, strain

The slum test had a value of 75mm. Control specimens are concrete with 100% cement which is compared with the strength performance of concrete containing 5%, 10%, 15%, 20% and 30% metakaolin. The result as shown in table 2

Table 2 Compressive Strength at Different Ages

Metakaoline % Replacement	Compressive Strength			
	3 days	7 days	28 days	90 days
0%	24.3	28.2	40.3	44.6
5%	25.2	26.5	37.8	41.9
10%	27	32.3	45	50.4
15%	28	33	46.1	52.4
20%	24.8	26	37.1	41
25%	19.3	23.4	33.2	37.5
30%	18	22	30	34

However, the results show that the strength development of the blended concrete is relatively close to the control. This can be clearly revealed when 5% and 10% achieved compressive strength of 37.8 MPa and 45 MPa respectively compared to 40.3 MPa of the control at 28 days.

Based on the results, it can be seen that the amount of metakaolinite presents in 5% replacement is not sufficient enough to enhance the compressive strength over the control as the replacement ratio is too small. The metakaolinite available only react with a portion of calcium hydroxide released from the cement hydration which limits the strength development at the later ages. The secondary CSH produced is limited to a certain numbers. However, the enhancement of these additional CSH gels is then overridden by the dilution effect. As the results, the blended concrete exhibits similar strength development compared with the control beginning from the third day onwards.

The concrete cubes with 15% replacement exhibits the best strength performance in this study. For 15% replacement of PC with metakaolin, the blended concretes exhibit higher strength than the PC at all ages. The strength increases over the control continue over the following ages until concrete with 15% replacement achieves compressive strength of 46.1 MPa, about 14.4% higher than the control. From the results, it is clear that among different replacement levels, the use of metakaolin at the replacement level of 15% performed the best, which resulted in the highest strength increase over the control concretes at all test ages.

The 20% replacement also exhibits similar strength development as the control. Compared to 5% and 10% replacement, the amount of metakaolinite exists in the blended concrete are probably too high. The quantity of calcium hydroxide produced from the hydration of cement is not enough to react with all the metakaolinite to produce extra CSH. The calcium hydroxide has been reduced to the minimum level while some metakaolinite are left out without any chemical reaction.

The compressive strength of the cubes with 25% and 30% replacement are generally lower than the control at all test ages. This is generally caused by the “dilution effect”. As the replacement rations exceed 15%, the amount of metakaolinite is in excess to react with calcium hydroxide. These extra metakaolinite produce an immediate dilution effect such that the water-cement ratio is reduced. Concrete strength is reduced in approximate proportion to the degree of replacement.

3.1. Slump Test

The workability of the mixture decreased by adding replacement cement with metakaoline. Slump height for the control specimen which is plain concrete was 75mm. Slump for concrete mixture which contains 15% metakaolin replacement was 55mm, which is 20.0% lower than the control specimen. Therefore, it shows that the metakaolin stiffen the mixture and lower the workability of the mixture.

3.2. Flexural Strength Test

Beam A serve as the control beam in this research and it result is compare with that of beam B which had 15% of cement replaced with metakaoline. The first crack load for the beam B was about 20kN. Which occurred at the middle of the span and the deflection was 8.3 mm, while the strain was 122 x 10^{-6}. The increased of load generate more cracks within the tension zone. The control beam (A) failed at 95.1kN with the deflection near failure of 14.66mm.

The ultimate load is slightly below that of beam B which is about 14.02% higher. Beam A had it first crack load at 15 kN and the deflection was 9.7mm. Strain at the first crack was 263×10^{-6}. The increment of load creates more multiple cracks. Beam B failed at 110.6kN with the deflection of 17.82 mm. In general, beam B is able to sustain higher load compare to beam A.

3.3. Deflection

From experimental, it is seen that the beam with 15% metakaolin deflect less, about 8.3mm compared to control sample with deflection 9.5mm. The deflections at ultimate load for all beams have shown that with 15% metakaolin cement replacement beams are capable of resisting more deflection before collapse. The collapse deflection for beam with 15% replacement was 17.82mm which is higher than control sample which is about 14.66mm.

The deflection obtain for both control specimens and 15% replacement are within the allowable limit provided by BS 8110. BS 8110 recommends an upper limit of span/250 for the deflection in order to satisfy the appearance and safety criteria of a structure. The ductility of reinforced concrete structures is also of paramount importance because any member should be capable of undergoing large deflections at near maximum load carrying capacity, providing ample warning to the imminence of failure. Teo (2006) mentions that members with a displacement ductility in the range of 3 to 5 has adequate ductility and can be considered for structural members subjected to large displacements. From this investigation, it was also observed that a metakaoline replaced concrete results in high ductile behavior.

3.4. Cracking

Cracking is one of the important data needed in this study. Beam A which is plain concrete had the first crack load at 15kN load while B at 20kN. This shows that beam B had higher first cracks load than beam A concrete. From the observation, it clearly shows that beam B has better performance than beam A concrete. It not only can sustain bigger loading about 83kN but also have smaller cracking size compare to beam A with about 68kN plain concrete. For both beams, the average widths for the cracks were 0.25 mm for beam A while the average width were 0.18mm for beam B. Concrete with 15% metakaolin content inhibit crack growth and crack widening. The number of cracks for beam A is more than beam B. The numbers of crack at middle span were seen to increase with the load.

The cracks forming on the surface of the beams were mostly vertical, suggesting failure in flexure. In most codes of practice, the maximum allowable crack widths lie in the range of 0.10 to about 0.40 mm, depending upon the exposure condition.

4. Conclusions

The following conclusions can be made on the basis of this study. The concrete with 15% metakaolin cement replacement give the optimum compressive strength. The behaviour of the concrete with partial replacement of portland cement by metakaolin, is significantly superior to concrete that use only portland composite cement as binder.

It was generally observed that the flexural behaviour of metakaolin concrete is comparable to that of ordinary Portland cement concretes and this investigation gives encouraging results for metakaolin to be used as cement replacement substitutes in the production of structural concrete.

Beam with 15% of MK7003 able to resist more deflection before failure which is about 17.82mm and 17.73% higher than control sample. Metakaolin concrete beams showed good ductility behaviour. All beams exhibited considerable amount of deflection, which provided ample warning to the imminence of failure. (5) From tested beams it shows that 15% metakaolin replaced concrete beam was able to resist more load about 20KN and 25% higher than control beam before initial crack occured The crack widths at service loads ranged between 0.18 mm to 0.25 mm and this was within the maximum allowable value as stipulated by BS 8110 for durability requirements, the crack at failure for all beams are flexure-shear failure

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