Enhancing the Properties of Laterite Rock Concrete using Metakaolin

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Abstract: ***The effect of replacing sand with metakaolin MK on the workability and strength properties of laterite rock concrete was investigated. MK was introduced at 0 %, 5%, 10% and 15% replacement levels for sand. Results show that as the percentage of MK increases, the workability as measured by the slump and compacting factor test reduces. However, the introduction of superplasticizer increased workability substantially and comparable to the control concrete consisting of granite aggregate. Furthermore, the compressive and splitting tensile strength measured at 3, 14 and 28 days showed optimum performance at 5% MK replacement beyond which there was decline on further addition of MK. Results also showed that the deflocculating effect of superplasticizers on MK consistently improved the compressive strength and splitting tensile strength of laterite rock concrete for all mixes.***

Keywords: Laterite rock concrete, metakaolin, superplasticizer, workability, compressive strength, splitting tensile strength

1. Introduction

As the demand for sustainability in the construction industry intensifies, the use of local available materials offer a more sustainable solution. Locally available construction materials are more economical, have lower embodied energy and are environmentally friendly [1] with reduced carbon emission especially in the transportation phase.

In most parts of the tropics, such as Africa, Asia and South America, the use of laterite a form of metamorphic rock for construction purposes is common. Concrete made from laterite rock as coarse aggregate is referred to as Laterite Rock Concrete LRC. Various research have been carried out to investigate the performance of laterite rock aggregate and LRC [2]–[7]. [8] studied the mechanical properties of concrete produced using laterite as partial replacement for coarse aggregate. Results reveal that as replacement level increases, compressive strength, flexural strength and elastic modulus reduces. However, results for 10% replacement was comparable to the control concrete. [4] showed that for LRC concrete mixes containing wholly laterite as coarse aggregate, a minimum water-cement ratio (w/c) of 0.6 is required to achieve medium (50 – 90 mm) workability. The result also reveals that the highest 28-day compressive strength of 25.2 N/mm^2 was obtained from 1: 1.5: 3 mix with w/c of 0.55 and a slump of about 25 mm. The low performance of laterite aggregate can be attributed to its high porosity leading to high water absorption and subsequent reduction in mechanical and durability properties of LRC [7], [9], [10].

To address the shortcoming of LRC, the use of metakaolin MK as a void filler in the concrete matrix is proposed. The particle size of MK range from 2 - 10 µm and a high specific surface area of 11 to 20 m^2/g. Metakaolin comes from the calcination of high quality kaolinitic clay at temperatures between 600 – 800°C. Due to its pozzolanic nature, MK has been used in concrete as partial replacement for cement. Several authors have demonstrated that metakaolin can be used to improve the strength properties of concrete [11]–[15]. [16] showed that for blended cement pastes, MK has a faster rate of early pozzolanic reaction than silica fume and fly ash. The study revealed that, at all ages (up to 90 days) tested, the highest compressive strength was recorded at 10% cement replacement of MK. Similarly, metakaolin has been found to decrease shrinkage and weight loss in concrete [14]. Also, improved concrete durability can be achieved through pore structure refinement leading to reduced permeability using metakaolin [14], [16]–[18]. Study by [19] showed that as the amount of metakaolin used as cement replacement increases from 0 to 15%, the porosity of the cement paste reduces.

However, research on the use of metakaolin as a partial replacement for fine aggregate in concrete is limited. This study will attempt to enhance the performance of LRC using metakaolin as a void filler.

2. Materials, Method and Testing

2.1 Materials

Laterite aggregate obtained from Nnewi, Anambra State was used wholly as coarse aggregate while granite aggregate was used as the control to produce conventional concrete. Their gradings are similar as shown in Fig. 1. River sand with fineness modulus of 2.6 was used as fine aggregate. The sieve analysis was conducted in accordance with ASTM 136. Ordinary Portland Cement manufactured by Dangote group and conforming to NIS 444-1:2003 was used as binder. Metakaolin MK, was used as partial replacement for fine aggregate. Table 1 show the physical properties of materials used for this research. Superplasticizer of the Polycarboxylate ether group complying with EN934-2 was used for this study. Portable water was used for mixing and curing concrete.

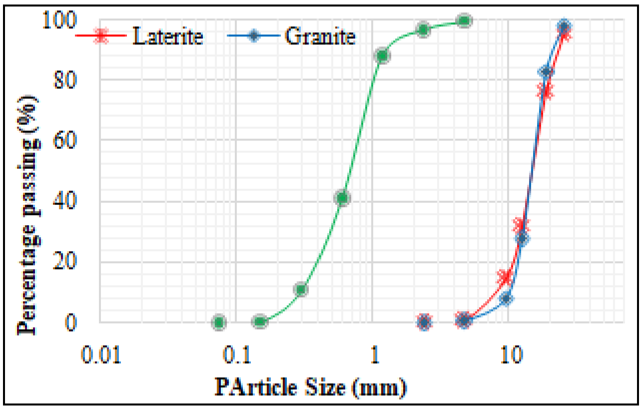

Figure 1: Particle size distribution of aggregates

Table 1: Physical properties of materials

Property	Metakaolin	Cement	Laterite	Granite
Water absorption (%)	-	-	4.8	0.69
Specific gravity	2.54	3.11	2.68	2.62
Specific surface area (m^2/g)	11.30	0.35	-	-
LA abrasion (%)	-	-	29.3	15.73

2.2 Method

Concrete nominal mix of 1: 1.5: 2 with w/c of 0.45 was adopted to obtain concrete of fairly good quality. MK was partially used to replace sand as fine aggregate at 0 %, 5 %, 10 % and 15 % by mass of sand. See Table 2. MK replacement levels were stopped at 15% because of difficulties (stiffness) witnessed in mixing above 15% using the mechanical mixer. Superplasticizer was added where necessary at a dosage of 1 litre/100 kg cement. This is within the manufacturer's dosage specification. A total of 9 different mixes were designed. For each mixture, 9 number 150 x 150 x 150 mm concrete cubes and 9 number 150 mm diameter by 300 mm height concrete cylinders were cast, compacted and cured for compressive strength and split tensile strength testing respectively. In all, a total of 81 cubes and 81 cylinders were used.

The following reference is used to denote the various mixes. L to represent laterite, M for metakaolin and S for superplasticizer. For instance, mix LSM_5 represents laterite concrete with superplasticizer and 5% metakaolin.

2.3 Testing

Workability was tested using the slump and compacting factor test in accordance with BS EN 12350-2:2009 and BS EN 12350-4:2009 respectively. Concrete demoulding was done after 24 hours, afterwards the concrete was cured by immersion in water. Compressive strength and split tensile strength tests were done in compliance with BS EN 12390-3-2009 and ASTM C 496 respectively at 3, 14 and 28 days. Three specimens were used for each testing age and the average of the three results taken.

Table 2: Proportioning of concrete mixes

Replacement Level	Notation	w/c	Constituents (kg/m^3)						SP (l)
			Water	Cement	Sand	Granite	Laterite	MK	
	Control	0.45	203	450	675	900	0	0	0
0%	LM0	0.45	203	450	675	0	900	0	0
	LSM0	0.45	203	450	675	0	900	0	4.5
5%	LM5	0.45	203	450	641	0	900	34	0
	LSM5	0.45	203	450	641	0	900	34	4.5
10%	LM10	0.45	203	450	607.5	0	900	67.5	0
	LSM10	0.45	203	450	607.5	0	900	67.5	4.5
15%	LM15	0.45	203	450	574	0	900	101	0
	LSM15	0.45	203	450	574	0	900	101	4.5

3. Results and discussion

3.1 Workability

3.1.1 Slump

Result of the slump test is shown in Fig. 2. The slump test reveals that mixes containing MK without superplasticizer consistently had zero slump. This could be attributed to two main reasons. The first is that the very tiny particles of MK with high surface area have high water demand [11], [13]. Secondly, the porosity and high water absorption of laterite aggregate could also be responsible for the poor slump recorded [7], [8].

It can also be seen that at each MK replacement level, the addition of superplasticizer increased slump significantly in comparison to the corresponding mix. This is due to the increased fluidity resulting from the adsorption of superplasticizer on the fine MK and cement particles, causing deflocculation of these particles and subsequent release of water to lubricate the system and effect air expulsion from the particles agglomerate [15], [20].

Results also show that for mixes containing superplasticizer, the slump reduced progressively as Mk content increased. This is because increasing MK content requires higher superplasticizer dosage for improved workability, but the dosage of superplasticizer for this work was kept constant. Similar results were obtained by [21].

3.1.2 Compacting Factor

As MK replacement level increased, the compacting factor marginally decreased, see Fig. 3. With reference to the control mix, the least values were obtained at 15% MK replacement with a reduction of 0.055 (5.7%) and 0.33 (34.2%) for mix with and without superplasticizer respectively. [22] also observed a slight variation of 0.1 in the compacting factor results for concrete containing up to 14% MK as replacement for cement. This minor variation of the compacting factor values irrespective of increased MK content can be attributed to the cohesive behavior of the MK blended concrete [22]. Also, as previously mentioned in the slump test results, it is observed that the deflocculating effect of superplasticizer on MK consistently improved compacting factor values for all percentages of MK tested.

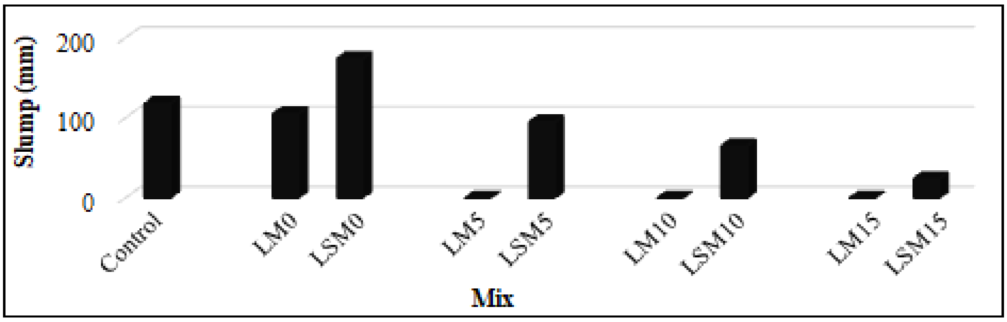

Figure 2: Slump test result

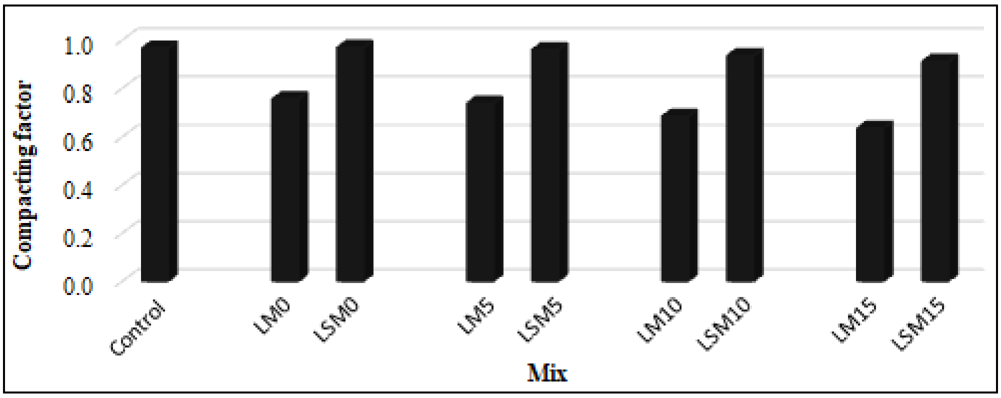

Figure 3: Compacting factor result

3.2 Compressive Strength

The result of compressive strength development with time of the various mixes is presented in Figs. 4 and 5. It was observed that the compressive strength of LRC without MK (LM_0) was lower than the control concrete at all ages tested. This is a consequence of the high porosity and water absorption of the laterite aggregate [4], [9]. At 5% MK, there was an increase in compressive strength with reference to the control concrete for all ages tested. At 3 days, percentage increase of 10.1% and 46.4% was recorded while at 28 days, increase of 1.2% and 51.6% were recorded for LM_5 and LSM_5 mixes respectively. Further addition of MK resulted in a decline in compressive strength. This is indicative that the optimum replacement percentage of sand with MK for LRC is 5%. Possible reason for this increased strength is the pozzolanic reaction of MK which accelerates hydration reaction [11], [17]. In addition, the introduction of MK improves bonding at the interfacial transition zone ITZ between cement paste and aggregate as well as increasing density of cement paste through micro filling which impacts positively on the compressive strength of the concrete [11], [14], [17].

Also, the introduction of superplasticizer to the concrete matrix resulted in compressive strength that were consistently higher than the corresponding mix at all ages tested. Similar result was obtained by [15]. According to [15], the very small MK particles have high surface energy and thus flocculate to form agglomerates having entrained air. This reduces reactivity and impacts negatively on compressive strength. As the quantity (percentage) of MK increases, the agglomerates with entrained air become larger thereby further decreasing the compressive strength of the concrete. On addition of superplasticizer, there is deflocculating and dispersion of the MK particles thereby enabling greater pozzolanic reaction and air expulsion resulting in increased strength. It then follows that increased MK percentage may require more superplasticizer dosage, but this study kept superplasticizer dosage constant, hence the drop in compressive strength as MK percentage increases.

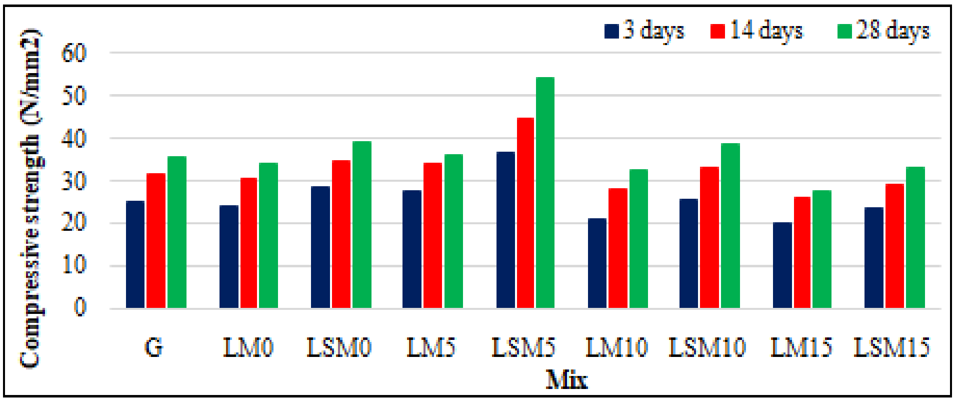

Figure 4: Compressive strength development of various mixes

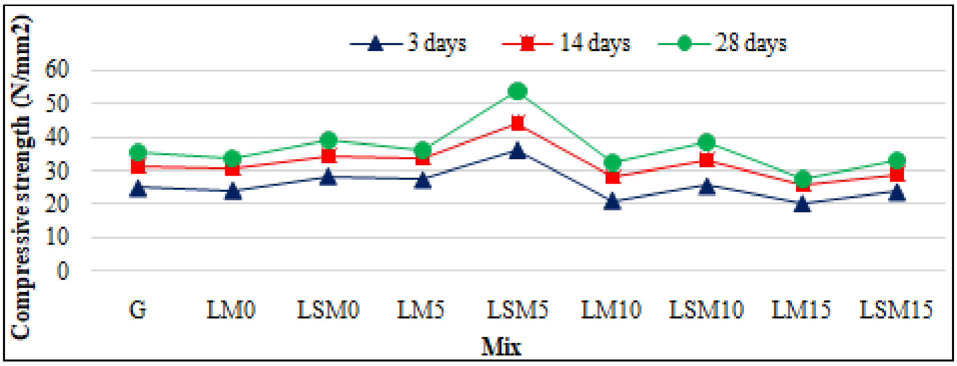

Figure 5: Compressive strength at different replacement levels

3.3 Split Tensile Strength

Figs. 6 and 7 show that the relationship between MK content and the splitting tensile strength development with age is similar to that of compressive strength as discussed earlier. Similar trends were observed in the works of [14] and [13]. Here also, the optimum tensile strength occurs at 5% MK content. It can also be seen that the use of superplasticizer increased tensile strength significantly. Nonetheless, there is a difference observed between the rate of strength development for compressive and split tensile strengths. Figs. 6 and 7 relatively show larger differences in values between the 3 days and 28 days split tensile strength in comparison with the values of compressive strength as seen in Figs. 4 and 5. On the average, at 3 days, 55% of the 28 day split tensile strength is developed and at 7 days, it is 76% for all the mixes containing MK. Whereas it is 70% and 89% of the 28 day compressive strength developed at 3 and 7 days respectively. This is indicative that for MK modified LRC, the rate of strength development is faster in compressive strength than tensile strength. Similar observations were made by [23] for conventional concrete.

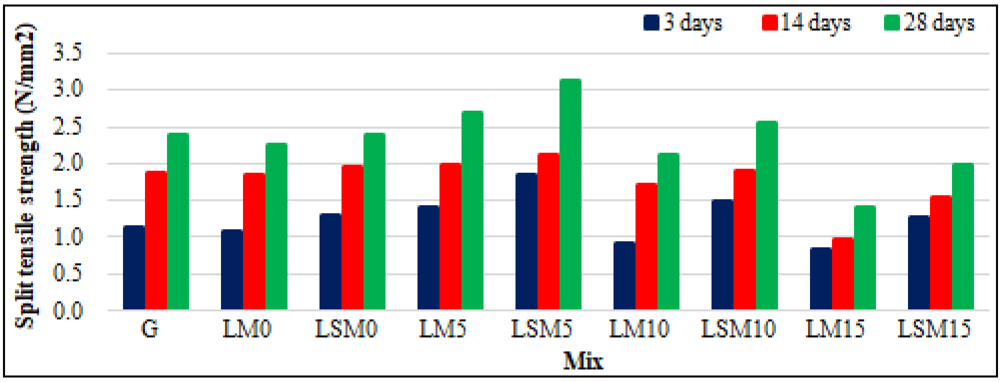

Figure 6: Split tensile strength development of various mixes

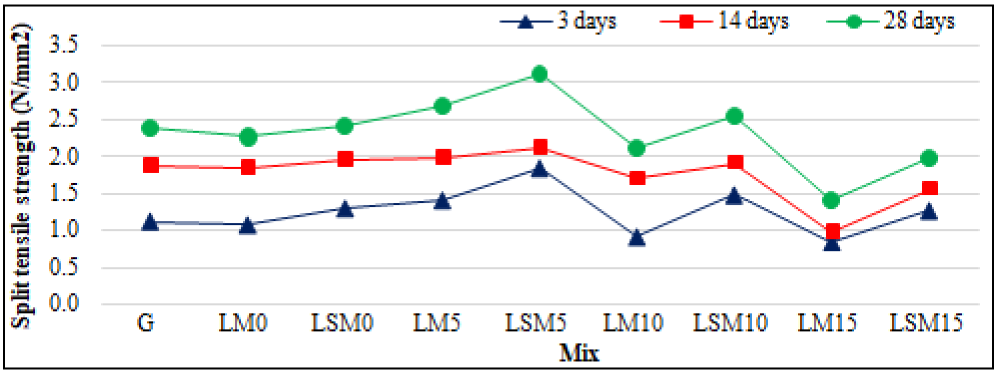

Figure 7: Split tensile strength at different replacement levels

4. Conclusion

The role of metakaolin in enhancing the properties of LRC has been studied and the following conclusions drawn from this research:

1) Metakaolin can be used to enhance the properties of LRC by partially replacing sand in the concrete matrix
2) The study showed that the optimum replacement level is 5% as it gave the most compressive and splitting tensile strength even above the control mix comprising of granite as coarse aggregate
3) The role of superplasticizer is sacrosanct in the use of metakaolin blended LRC as it significantly improves the workability, compressive and tensile strength of the concrete.

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