Load - Deflection Characteristics of Reinforced Concrete and Reinforced Latecrete Beams at Mid-Span

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Abstract
A laboratory Investigation of the Flexural Strength of Latecrete materials was carried out. The laterite used falls under AASHTO soil classification A-7-6 (10) with low plasticity clay (CL) according to the Unified soil classification system. This laterite is within zone four gradation characterized by fine laterite and has kaolinite as its dominant clay mineral. The Experimental programme involves the fabrication of twenty beams of concrete and latecrete materials; and testing them for flexural strength. Tests show that The Flexural strength recorded for plain concrete beams was 2.89 N/mm^2, while plain latecrete beams has a value 1.44 N/mm^2. The flexural strength of 13.58 N/mm2 was recorded for the reinforced concrete beams and 7.80 N/mm^2 for reinforced latecrete beams, indicating that the flexural strength of latecrete beam is approximately 50% of that of concrete beam specimens. The load-deflection behaviors of the beams are essentially linear within the elastic range of loading. Based on the findings of this investigation, it was observed that the behavior of latecrete is similar to that of concrete; however, the concrete materials showed better strength characteristics than the latecrete materials.

Keywords: Concrete, Latecrete, sand, Reinforcement and flexural strength.

1. Introduction

In recent times, the cost of concrete production has increased, given rise to the development of construction materials from cheap and readily available material sources which reduces construction costs and yet remains consistent with the advancing state of the indigenous technology (Adepegba, 1975a; Osunade, 2002; Ata, 2003).

Lateritic soils belong to the category of cheap and readily available materials. Lateritic soils are known to be available in large quantities all over Nigeria as well as in most tropical countries of the world. They are essentially products of tropical or sub-tropical weathering, usually found in areas where natural drainage is impeded (Ata, 2007). Laterite has been investigated as a replacement of sand in the conventional normal cement concrete (Adepegba, 1975a; Osunade, 2002; Ata, 2003). Concrete in which the sand component is partially or wholly replaced by laterite is called latecrete, LATCON or laterized concrete (Adepegba, 1975a; Ata, 2007). The paucity of information on the properties of latecrete led to low knowledge of the material.

There is skepticism in the acceptance of Latecrete as a construction material as local codes and specifications for the material are not yet available (Ata, 2007). Thus, the development and standardization of routine tests for determining the mechanical properties of this material is of unquestionable importance. This is because, the rewards can be great in design economy, as knowledge of this kind enables the Engineer to employ logical factors of safety rather than conservative factors of ignorance (Harmer, et al, 1964).

Although a good number of researchers concentrated on compressive strength as a fundamental property in examining the strength of latecrete. (Adepegba, 1975a; Lasisi, et al, 1990; Ata, 2003). However, when considering its use in a beam element of a structure, the flexural strength is also important as it models how a beam is normally loaded; and this necessitates the choice of this topic.

Adepegba (1975a) in a study replaced sand in the normal cement concrete with laterite fines, and this he referred to as laterized concrete. He intimately mixed cement, laterite fine and gravel in the following proportions by weight: 1:1:2, 1:1.5:3 and 1:2:4, and made the following observations:

(a) Laterized concrete requires more water than normal cement concrete.

(b) The laterized concrete will be too dry if the W/C ratio is less than 0.5 and too wet if higher than 1.0 for the mix proportions (1:1:2, 1:1.5:3, and 1:2:4), while that of the normal cement concrete ranges between 0.3 and 1.2.

(c) (i) The minimum and maximum W/C ratio for 1:2:4 mix by weight of laterized concrete are 0.65 and 0.95 respectively.
(ii) For 1:1.5:3 and 1:1:2 mix are 0.55 and 0.85 respectively.

(d) For practical purposes, a W/C of about 0.75 is recommended for 1:2:4 mix by weight since this would yield a compressive strength of 18.5 Mpa (18.5 N/mm^2) in 28 days and a W/C of about 0.65 for 1:1½:3 and would yield a compressive strength of about 21.45 N/mm^2; and 23.59 N/mm^2 for 1:1:2 in 28 days.

He further observed that the compressive strength at 7-days was about 40 – 60% of the compressive strength at 28 days, while at 14-days, the compressive strength was about 70 -80% of the 28 days compressive strength.

In another study, Balogun and Adepegba (1982) discovered that the most suitable mix of laterized concrete for structural purposes is (1:1½:3), using batching by weight with a water/cement ratio of 0.65, provided that the laterite content is kept below 50 percent of the total fine aggregate content. Lasisi, et. al. (1990) have shown that the durability of laterized concrete and laterite/cement mortar specimens can be enhanced by the low permeability characteristics of the lateritic soil contents of such specimens.

In a study on a similar material, Ejeh (1982) investigating the compressive strength of 400 mm x 150 mm x 150 mm soilcrete hollow blocks, made the following observations:

(i). that properly manufactured soilcrete blocks can fully satisfy the requirements imposed by codes of practice.
(ii). the soilcrete hollow blocks have an average wet/dry compressive strength ratio of 0.65.
(iii). the soilcrete hollow blocks have a minimum wet/dry compressive strength ratio of 0.42.

Investigating the curing methods for soilcrete hollow blocks specimens, Ejeh (1990) recommended that for standard tests and quality control, immersion in water is more appropriate to laboratory work since spraying may be uneven and also the quality of water used may be doubtful. However, soilcrete hollow blocks from the study fully developed its dry compressive strength after curing by spraying with water and covering with water-proof materials for 7 days.

Abejide (1997) in a study on soilcrete blocks suggested that A6 grouping of lateritic soil suitable for stabilized soilcrete blocks should be based on colour, particle size distribution, chemical analysis, physical and structural properties, and morphology. Furthermore, he stated that uniform pressure is required on the blocks surfaces to ascertain its true compressive strength; a plate that distributes the pressure from the compressive testing machine is required.

Ola (1977) reported that soils with liquid limit less than 40 and clay content up to about 20% are suitable for stabilization and suggested that table 1 below should serve as the guide to selection of soils for stabilization:

Table 1 Selection guide for soils suitable for stabilization

Physical properties	For Permanent Urban Buildings	For Rural Housing with low rainfall
Clay content	5 – 20%	5 – 30%
Sand content	33% minimum	40% minimum
Liquid limit	40% minimum	50% minimum
Plasticity index	2.5 – 22%	2.5 – 30%
Optimum moisture content	10 – 14%	7 – 16%

After Ola (1977)

Neville (1995) opined that laterite could rarely produce concrete stronger than 10Mpa. However, Osunade (2002), and Ata (2003) proved this finding not to be true and submitted that laterite could produce concrete of higher grades.

In a study on the effect of mix proportion and reinforcement size on the anchorage bond stress of laterized concrete, Osunade and Babalola (1991) established that both variables have a significant effect on the anchorage bond stress between plain round steel reinforcement and laterized concrete, and that it increases with increase in the size of reinforcement.

In another study by Osunade (1994), he established that increase in shear and tensile strength of laterized concrete was obtained as grain size ranges and curing ages increased. Also, greater values of shear and tensile strengths were obtained for rectangular specimens than those obtained for cylinders.

The following major conclusions emerged from the experimental study reported by Ata (2007) on the effect of varying curing age and water/cement ratio on the elastic properties of laterized concrete:

(i). The modulus of elasticity of laterized concrete lies between 7000 and 9500 MPa, while that of deformability lies between the range of 5000 and 6000 MPa.
(ii). Modulus of elasticity and modulus of deformability of laterized concrete increase with an increase in curing age.
(iii). The value of modulus of elasticity of laterized concrete is always higher than its corresponding modulus of deformability.
(iv). The richer the mix; the higher the moduli of elasticity and deformability of laterized concrete.
(v). The stronger the laterized concrete; the higher the modulus of elasticity and the modulus of deformability.
(vi). Any water/cement ratio that will give laterized concrete high strength will increase its modulus of elasticity and modulus of deformability.

Osunade, et al. (1990) investigated the shear and tensile strength properties of laterised concrete under laboratory temperature of 20±1°C. They observed that, as in normal concrete, the strength development of test specimens was more rapid at an early curing age than at later age. A higher percentage of the long-term shear and tensile strength of laterised concrete was significantly acquired at an early curing age.

Salau (2003) investigated long-term deformation of short columns of laterized concrete without taking into consideration the change in temperature and concluded that laterized concrete specimens experience more creep and shrinkage deformation when compared to their corresponding normal concrete specimens. A consistent pattern of creep-time curves in all cases of laterite content was obtained. The shrinkage-time curves were also observed to be consistent but different from the creep-time curves.

Ikponmwosa and Falade (2006) reported on the study of strength properties of fibre-reinforced laterised concrete under normal laboratory temperature. A consistent trend of increase in strength with age was observed in the specimens. A proportion of 45% laterite content as replacement of sharp sand in concrete produced the highest compressive strength. At this laterite content, a reduction of 18% in the cost of fine aggregate in concrete was obtained at the prevailing market price. Although the strength characteristic of laterised concrete was found to be generally lower than that of normal concrete, it was sufficient for use in general concrete work. Concrete with 25% laterite content in the fine aggregate compared favourably with those of normal concrete of similar mix proportion by weight and water/cement ratio, and thus was evidently desirable for use in the determination of the effect of heat on laterised concrete.

Oluwaseyi and Mnse (2007) investigated the weathering characteristics of laterised concrete with laterite-granite fines ratio as a factor in ascertaining its suitability as a substitute for the conventional fine aggregate. They found that the compressive strength of laterised concrete with laterite-granite fines decreased when subjected to alternate wetting and drying. It was also observed that laterised concrete with 40-60% laterite-granite fines subjected to a temperature variation range of 75-125°C attained compressive strength of 22.52 N/mm^2. However, the critical failure temperature of the laterised concrete was not ascertained.

Although a good number of researchers concentrated on compressive strength as a fundamental property in examining the strength of latecrete. (Adepegba, 1975a; Lasisi, et al, 1990; Ata, 2003). However, when considering its use in a beam element of a structure, the flexural strength is also important as it models how a beam is normally loaded; and this necessitates the choice of this topic.

2. Materials and Methods

2.1. Cement

Ordinary Portland cement conforming to BS EN 197-1[12a] specification was used. Table 2.shows the physical properties of cement used compared with code specification.

Table 2 Comparison of results of Cement tests with Code specifications

S/No.	Parameter	Value	Code Specifications BS EN 197-1[6b]
01	Fineness	0.05	0.01 – 0.06
02	Consistency	31%	26-30%
03	Initial Setting time	80 minutes	≥ 45 minutes
04	Final Setting time	170 minutes	≤ 375 minutes
05	Soundness	1.0 mm	≤ 10 mm
06	Mortar Cube Compressive Strength (7 days)	21.53 N/mm^2	≥ 16 N/mm^2

(Each value is an average of three)

2.2. Sand

River sand having bulk density 1352 kg/m3 and fineness modulus 2.78 was used. The specific gravity was found to be 2.58.The particle size distribution is plotted as shown in figure 1.

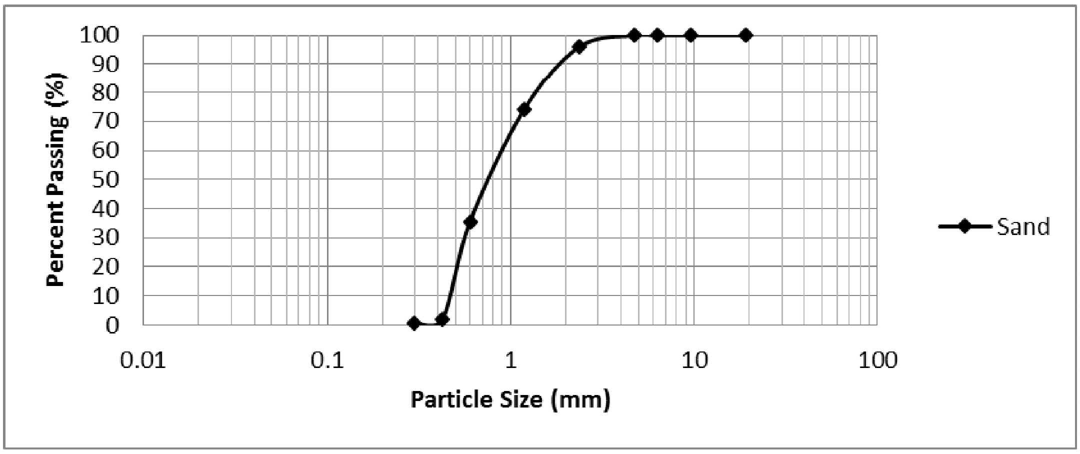

Figure1. Particle size distribution curve of Sand

The silt content obtained is 2.23 per cent and is less than 10 per cent as specified by code (BS EN 1008 (2002)). The silt content of the sand is satisfactory to the code.

2.3. Laterite

Laterite having bulk density 1594 kg/m3 and fineness modulus 2.53 was used. The specific gravity was found to be 2.6. The particle size distribution is plotted as shown in figure 2. It shows that 93.02 per cent passes BS sieve size 600µm which shows that the laterite is classified as belonging to zone four gradations, characterized by fine laterite, which is poor for concrete in accordance to BS 882 (1992). The chemical composition of the Laterite is presented in table 3.

Table 3. Chemical Composition of samara laterite

Mineral	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	Mn_2O_3
Composition (%)	24.0	35.60	0.28	27.40	0.22	2.0

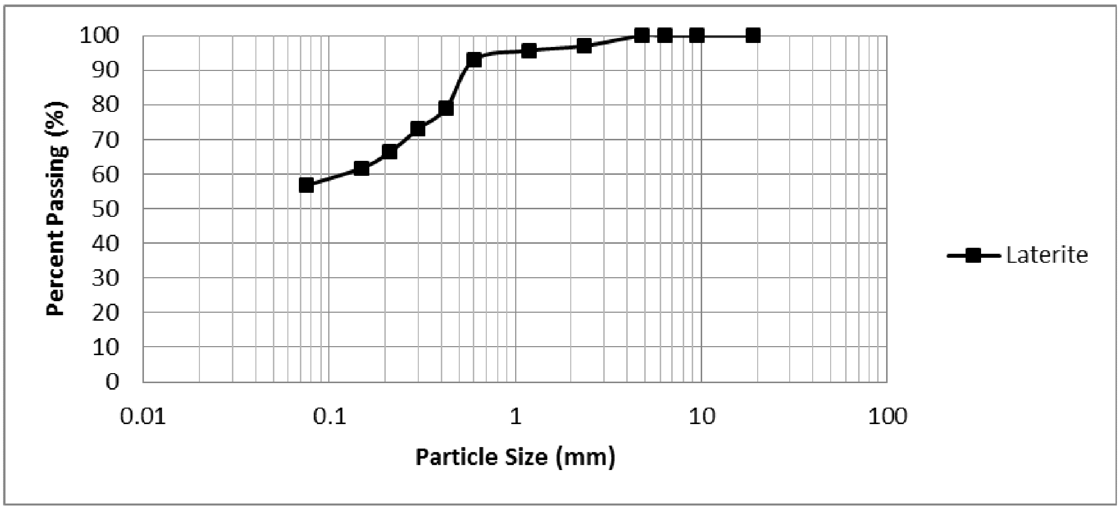

Figure 2 Particle size distribution of laterite

2.4 Coarse Aggregates

The particle size distribution of coarse aggregate after sieving is shown in figure 3. It shows that the coarse aggregate is well graded which is good for concrete production.

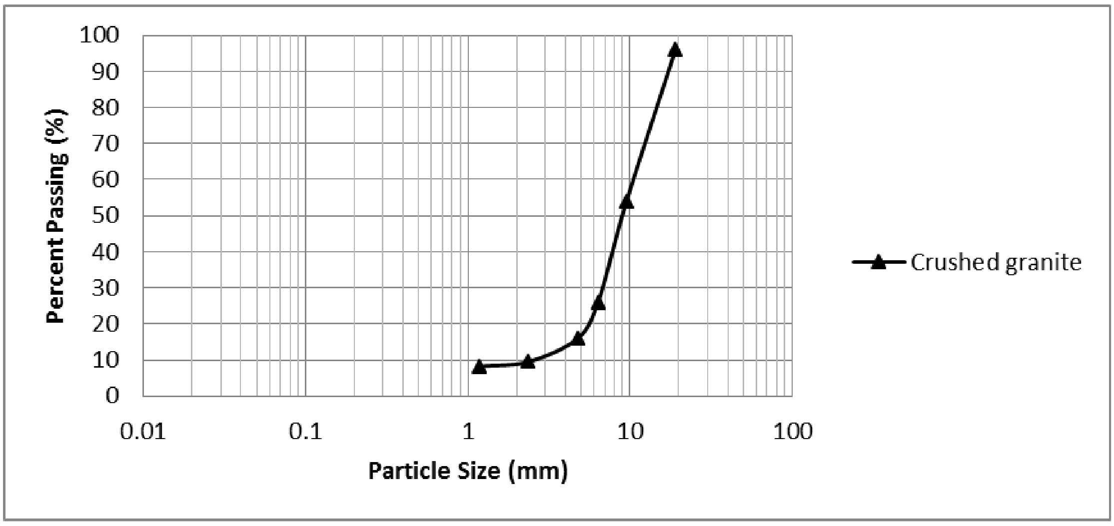

Figure 3 Particle size distribution of Coarse aggregates

The results obtained from coarse aggregates tests is summarized in table 4 and compared with Code specifications.

Table 4 Comparison of results of Coarse aggregates tests with Code specifications

S/No.	Parameter	Value	Code Specifications BS 812 (1985)
01	Specific gravity	2.6	2.4 – 2.9
02	Flakiness Index	14.12%	35% Max.
03	Elongation Index	14.70%	35% Max.
04	Aggregate Impact Value	41.9%	≤ 45%
05	Aggregate Crushing Value	19%	30% Max.

2.5 Reinforcements

The Summary of the characteristic strength and elongation for the high tensile bar is as shown in table 5 below.

Table 5 Comparison of results of reinforcement tests of high yield bars with Code specifications

S/No.	Parameter	Value	Code Specifications BS 4449 (1997)
01	Characteristic Strength	394 N/mm^2	460 N/mm^2
02	Ultimate Strength	606 N/mm^2	≥429.4 N/mm^2
03	Elongation	16%	≥12%

From table 5, it is observed that the characteristic strength of Y12 bars is 394 N/mm^2 which is less than the code specification of 460 N/mm^2, indicating that it failed the test in the characteristic strength parameter. This indicates that the high yield bar may be a mild steel bar material that is retreaded as high yield. However, the ultimate strength and elongation are 606 N/mm^2 and 16% respectively, which are within the code specifications.

The Summary of the characteristic strength and elongation for the mild steel bars is as shown in table 6 below.

Table 6 Comparison of results of reinforcement tests of mild steel bars with Code specifications

S/No.	Parameter	Value	Code Specifications BS 4449 (1997)
01	Characteristic Strength	391 N/mm^2	250 N/mm^2
02	Ultimate Strength	428 N/mm^2	≥429.1 N/mm^2
03	Elongation	19%	≥22%

2.6. Water

Pure and clean tap water fit for drinking was used.

2.7. Concrete and latecrete mix proportion

The mix ratio used for each mix is 1:2:4 which mean one part cement to two parts sand/laterite to four parts coarse aggregates by weight as shown in table 7.

Table 7 Weight of ingredient per m^3 of concrete/ latecrete

S/NO	INGREDIENTS	Weight for concrete(KG)	Weight for latecrete(KG)
1	cement	72.13	69.80
2	Fine aggregate	144.26	139.60
3	Coarse aggregates	288.51	279.21
4	Water	36.06	34.90

2.8. Test specimens and test procedure

Twenty beams measuring 150 x 150 x 750 millimeters were cast as beam specimens. The beam specimens were numbered B01, B02… B20. B01 implies beam number 01 and B02 implies beam number 02 to B20. B01 or B02 does not mean B01 is better than B02 but simply for identification purposes.

Beam numbers B01 to B10 are control beams. This means the beams were cast using cement, sand, coarse aggregates and water while B11 to B20 were cast using cement, laterite, coarse aggregates and water. Beam numbers B01 to B05 and B11 to B15 are reinforced, while B06 to B10 and B16 to B20 are of plain concrete and latecrete respectively. These beams were cured after casting for 28 days prior to crushing.

The above design mix ratio was first mixed thoroughly without water in both cases and after thorough mixing, a water cement ratio of 0.75 is used for Latecrete and 0.5 for Concrete beam in accordance to BS 1881 part 3 (1985) and (Adepegba, 1975). Mortar biscuits of 25 millimeters thick were used to provide concrete cover of 25 millimeters to the beams. After mixing with water to obtain a consistency, the mix is poured into beam mould and compacted, and well toweled smooth. After twenty four hours, it was demoulded and cured for the required age. As earlier stated, some of the beams (both concrete and latecrete) are not reinforced. The reinforced beams are reinforced with 2Y12 bottom and 2Y12 top, with shear reinforcements of R6 @ 162.5 c/c spacing. The details of the reinforcements are shown in figure 4.

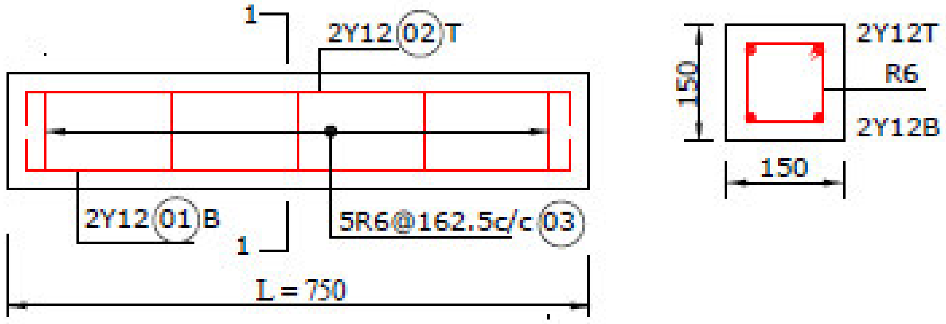

Figure 4 Longitudinal details of Beam/Section

The beam specimen was loaded in a three point flexural test set up as shown in figure 5.The deflection measurement of the beam at the mid-span and at equidistant opposite sides of mid-span were measured using dial gauges mounted at points a, b, c as shown in figure 5.

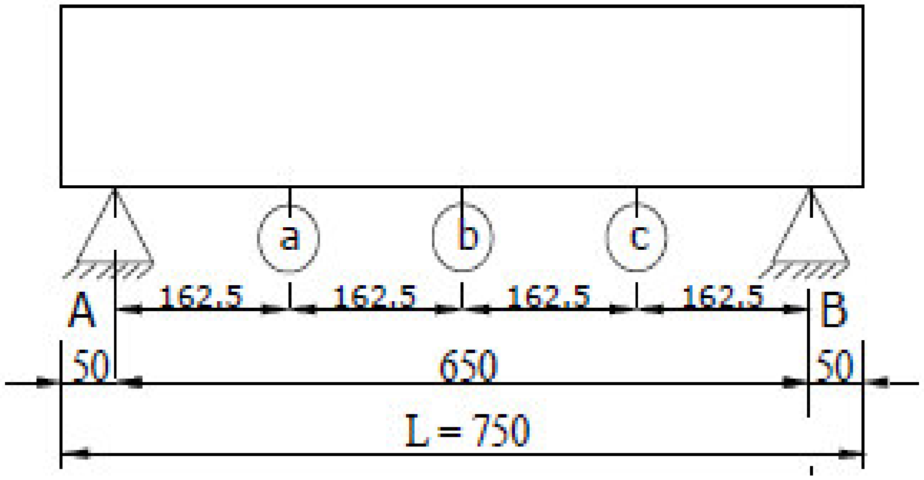

Figure 5 Position of Dial guages

3. Result and Discussion

3.1 Flexural strength of beam specimens

The average values of the flexural strength of the Beams are as shown in Table 8.

Table 8 Average Flexural strength of Concrete and Latecrete Beams

S/No.	Beam No.	Plain/Reinforced	Average Flexural Strength (N/mm2)
01	B01 – B05	Reinforced Concrete	13.58
02	B06 – B10	Plain Concrete	2.89
03	B11 – B15	Reinforced Latecrete	7.80
04	B16 – B20	Plain Latecrete	1.44

(Each is an average of five test result)

From Table 8, it is observed that the flexural strength of latecrete beams is about half of that of concrete beams.

3.2 Load - deflection characteristics of reinforced concrete and reinforced latecrete beam specimens at mid-span

The combined load – midspan deflection curve for all the reinforced concrete beams of B01 to B05 is as shown in figure 6 below. It can be observed that the shape of the figure is approximately linear up to a load of 15 kN for the reinforced concrete beams. Thus it can be said that the load mid-span deflection for reinforced concrete beam is of linear proportion up to 15 kN load. The corresponding mid-span deflection at this load is approximately 8 millimeter. Beyond this load, the load – midspan deflection from these figure are non-linear with increase in load with little or no increase in the corresponding deflection. Thus internal cracks within the beams are being formed absorbing the load and with little or no deflection. The average failure load at mid-span for reinforced concrete beam of B01 to B05 is 47 kN with a corresponding deflection of 11.67 millimeter.

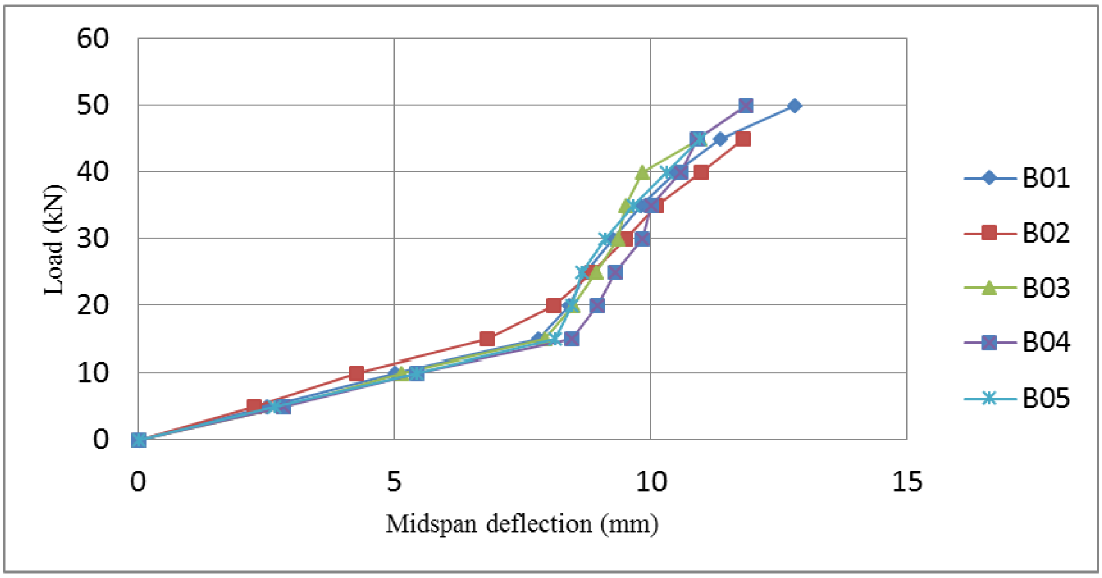

Figure 6 Load – midspan deflection for reinforced concrete beams, B01 to B05

For the latecrete, it was observed that the reinforced latecrete beams exhibit the same behaviour as described above for the reinforced concrete beam. The only difference is that the curve is linear up to a load of 10 kN for all the reinforced latecrete beams of B11 to B15. The corresponding midspan deflection for the load of 10 kN is approximately 6 millimeters. From 10 kN value, the latecrete beam becomes non-linear in behaviour. Thus in the latecrete beams, cracks forms beyond 10 kN load. Therefore, the latecrete beams shows lower load and deflection at elastic limit. The maximum load at failure for the reinforced latecrete beams is 27 kN and with a corresponding midspan deflection of 10.88 millimeter. Figure 7 shows the combined graph of load – midspan deflection of the reinforced latecrete beams.

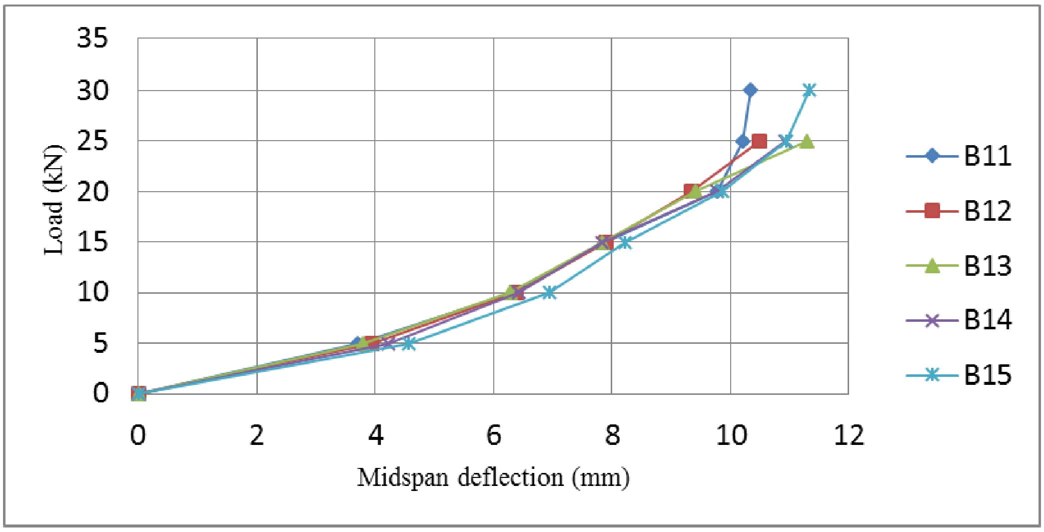

Figure 7 Load – midspan deflection of reinforced latecrete beams B11 to B15

Table 9 Approximate values of average Elastic load, average midspan deflection at elastic load, average failure load and average midspan deflection at failure load

S/No.	Beam No.	Approximate average Elastic load (kN)	Approximate average midspan deflection at elastic load (mm)	Approximate average failure load (kN)	Approximate average midspan deflection at failure load (mm)
01	B01 – B05	15	8	47	11.67
02	B11 – B15	10	6	27	10.88
03	% of latecrete beam/concrete beam	67	75	57	93

Even though the Reinforced concrete beams exhibit higher load at failure, the midspan deflection at failure of the latecrete is 93 percent of the concrete beam. This implies that Reinforced concrete beams is more ductile than the reinforced latecrete beams.

3.3 Load - deflection characteristics of plain concrete and plain latecrete beam specimens at mid-span

Figures 8 show the combined load – midspan deflection shape of plain concrete beam specimen of B06 to B10, up to failure load. It can be observed that the shape of the figure is approximately linear up to a load of 2.5 kN for the plain concrete beams. Thus it can be said that the load mid-span deflection for plain concrete beam is of linear proportion up to 2.5 kN load. The corresponding mid-span deflection at this load is approximately 3.4 millimeter. Beyond this load, the load – midspan deflection from these figures are non-linear with increase in load with little or no increase in the corresponding deflection. Thus internal cracks within the beams are being formed absorbing the load and with little or no deflection. The average failure load at mid-span for plain concrete beam of B06 to B10 is 10 kN with a corresponding deflection of 4.05 millimeter.

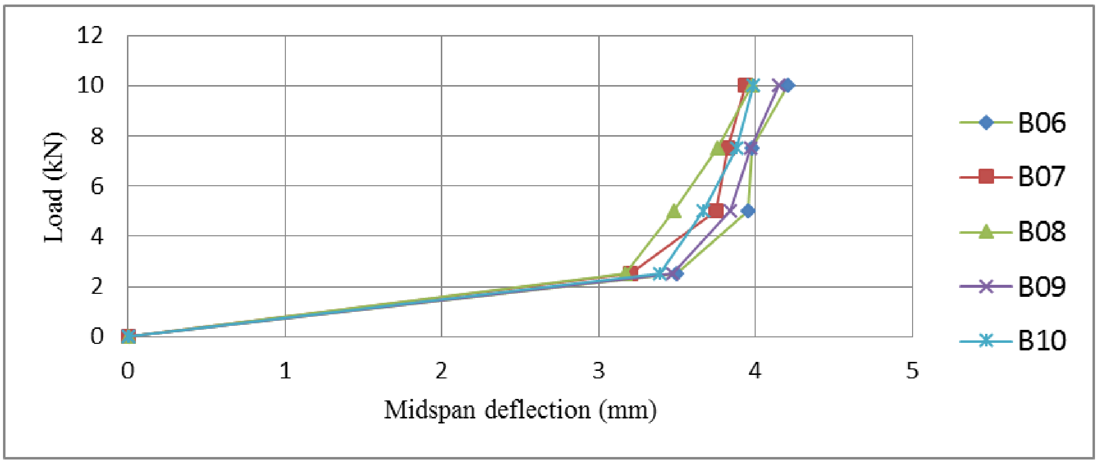

Figure 8 Load – midspan deflection of plain concrete beams of B06 to B10

Figures 9 show the combined load – midspan deflection shape of plain latecrete beam specimen of B16 to B20, up to failure load. It can be observed that the shape of the figure is approximately linear up to a load of 2.5 kN for the plain latecrete beams. Thus it can be said that the load mid-span deflection for plain latecrete beam is of linear proportion up to 2.5 kN load. The corresponding mid-span deflection at this load is approximately 3.8 millimeter. Beyond this load, the load – midspan deflection from these figures are non-linear with increase in load with little or no increase in the corresponding deflection. Thus internal cracks within the beams are being formed absorbing the load and with little or no deflection. The average failure load at mid-span for plain latecrete beam of B16 to B20 is 5 kN with a corresponding deflection of 3.97 millimeter.

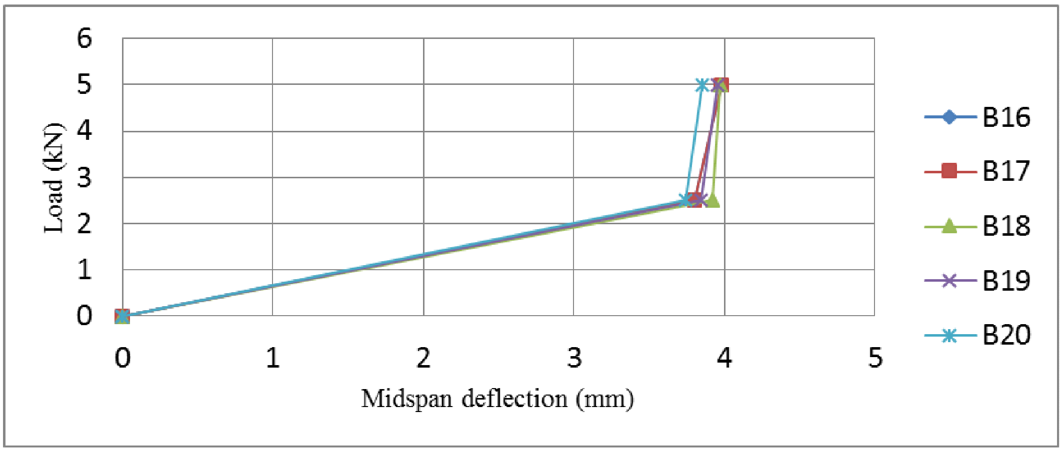

Figure 9 Load – mid span deflection of plain latecrete beams of B16 to B20

The discussions on the load – midspan deflection characteristics of the plain concrete beams and plain latecrete beams above is summarized in table 10.

Table 10 Approximate values of average Elastic load, average midspan deflection at elastic load, average failure load and average midspan deflection at failure load for plain concrete beams and plain latecrete beams

S/No.	Beam No.	Approximate average Elastic load (kN)	Approximate average midspan deflection at Elastic load (mm)	Approximate average failure load (kN)	Approximate average midspan deflection at failure load (mm)
01	B06 – B10	5	3.4	10	4.05
02	B16 – B20	2.5	3.8	5	3.97
03	% of latecrete beam/concrete beam	50	112	50	98

Even though the plain concrete beams exhibit higher load at failure, the midspan deflections of the two beams at failure is almost equal. This implies that plain concrete beams are more ductile than the plain latecrete beams.

4. Conclusions

Based on the present and experimental investigation studies, the following conclusions were drawn.

1. The cement used for the research satisfied the requirements of BS EN 197-1:2000, for Ordinary Portland Cement and thus is of good quality.
2. The coarse aggregates are within specified grade limits in BS 812:1985. The specific gravity, flakiness index, elongation index, aggregate impact value and aggregate crushing value are 2.60, 14.12%, 14.70%, 41.90% and 19.00% respectively.
3. The flexural strength of reinforced concrete beams is 13.58 N/mm^2 and the flexural strength of reinforced latecrete beams is 7.80 N/mm^2. The flexural strength recorded for the plain concrete beams is 2.89 N/mm^2, while that of the of plain latecrete beams is 1.44 N/mm^2.
4. The concrete beam specimens are more ductile than the latecrete beam specimens.
5. The load-deflection behaviours of the beams are essentially linear within the elastic range of loading.

5. Recommendation

Stress - strain characteristics of reinforced concrete and reinforced latecrete beam specimens at midspan should be investigated.

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