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Full Paper

Effect of heat on laterised concrete

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Abstract: This study presents the results of investigation of the effects of temperature variation on the compressive strength of laterised concrete. Cube specimens were cast, cured in water at ambient laboratory temperature and subjected to different temperature regimes before testing. A concrete mix ratio of 2:3:6 (cement: laterite/sand: granite) with water/cement ratio of 0.65 was adopted for this investigation. The laterite content in the fine aggregate was varied from 0 to 100% at 25% interval. Specimens cured for 7 and 28 days were subjected to uniaxial compressive loading tests at room and elevated temperatures of 250, 500 and 750°C. The results show that normal concrete cannot withstand appreciable load above 250°C while laterised concrete with 25% laterite in the fine aggregate is able to resist higher load with increase in age and at temperature up to 500°C. It is also observed that there is no appreciable increase in strength at higher temperatures. The peak compressive strength value of 30.44 N/mm^2 is recorded for the mix with 25% laterite-75% sand at 500°C. This is an indication that the strength of laterised concrete is generally sufficient for use at elevated temperature not exceeding 500°C.

Keywords: laterite, laterised concrete, compressive strength

Introduction

Laterised concrete is one in which the fine aggregate has been partially or wholly substituted with laterite soil in its natural form [1-2]. This soil in readily available in Nigeria and constitutes one of the locally and readily available but underutilised building materials. Its neglect as a structural engineering material is associated with the uncertainty of its strength and other structural

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characteristics. Osunade et al. [3] investigated the shear and tensile strength properties of laterised concrete under laboratory temperature of 20±1^{o}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 [2] investigated long-term deformation of short columns of laterised concrete without taking into consideration the change in temperature and concluded that laterised 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 [4] 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 [5] 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^{o}C attained compressive strength of 22.52 N/mm^{2}. However, the critical failure temperature of the laterised concrete was not ascertained.

Nijland and Larbi [6] reported that heating of concrete by fire might result in a variety of structural failure such as cracking, spalling, debonding of aggregate and rebars, expansion and mineralogical/chemical changes such as discolouration, dehydration and dissociation. They stated that when a concrete structure is exposed to fire, differential expansion and contraction of various components and constituents within the concrete take place. Also, depending on the period of exposure to the fire, considerable changes may take place in a structure ranging from surface cracking and spalling, discolouration of the concrete, excessive expansion, buckling, warping and loss of strength of reinforcement if present, to cracking around and across aggregate, loss of bond to aggregate and reinforcement, and internal cracking within the cement paste. The failure temperature, however, was not ascertained. St. John et al. [7] stated that with regard to cement paste, evaporation, dissolution, dehydration and dissociation of ettringite, gypsum, calcium hydroxide, calcium carbonate

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and other phases such as calcium silicate hydrates in the cement paste may occur. The causes of this phenomena need to be ascertained.

Hansen and Ericsson [8] studied the effects of temperature change between room temperature and 100oC on the behaviour of cement paste, mortar and normal concrete under load. Results of their investigation show that cement paste and mortal beams deflect excessively when heated after application of load. Their findings also indicate that deflection occasionally leads to failure at low stresses and after moderate heating. It was also observed that deflection increases with higher rate of heating and the temperature at failure is lower for cement paste than for cement mortar. Likewise, deflection was observed to be large and the temperature at failure lower for saturated beams than for dry beams. Lastly, the researchers opined that rapid rates of heating permanently reduce the modulus of elasticity of cement mortar: an indication of internal destruction of the material structure. The study further concluded that thermal cycling leads to excessive deflection and occasionally to failure. It is, however, important to know the behaviour of normal concrete at higher temperature up to 1000^{o}C.

Salau [9] presented a report of comparative study of heat-resistant characteristics of normal concrete and concrete containing basalt as aggregate. The study revealed that the water adsorption and porosity of basalt concrete falls within an acceptable range for normal refractory material, and that while basalt concrete specimens display some coherence and stability in volume expansion, the normal concrete starts chipping, cracking and spalling at temperature above 450^{o}C. Furthermore, at the end of the first heating-cooling cycle, the subsequent cycles have no significant effect on the weight loss of both types of concrete, and at the end of the third heating-cooling cycle, the normal concrete has lost its entire strength while the basalt concrete still shows more than 17% residual compressive strength which it retains even after the sixth cycle.

Castillo [10] reported on the effect of transient high temperature on the uniaxial compressive strength of high-strength normal concrete. The temperatures studied varied from 100 to 800oC. The presence of loads in the structure was simulated by preloading the test specimens during the heating period. It was found that exposure to temperatures between 100-300^{o}C reduces the compressive strength of high-strength concrete by 15-20%. For temperatures between 400-800^{o}C, the compressive strength decreases to 30% of that at room temperature. A third of the preloaded specimens failed explosively during the heating period. In the remaining specimens the presence of a preload had a beneficial effect and a smaller loss of strength was observed compared to unstressed specimens. The author concluded that exposure to high temperatures causes the modulus of elasticity to decrease in all specimens irrespective of the preload condition and the strength of concrete.

Laterised concrete has been studied for its suitability for use in the construction of structural members. However, the effect of heat on this type of concrete is not well documented. Due to the plasticity and fineness of laterite fines compared to sharp sand, the effect of temperature variation will definitely influence the strength characteristics of laterised concrete. This work therefore aims to study its performance when exposed to different temperature regimes.

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Materials and Methods

The fine aggregate (i.e. sharp sand) used in this study was obtained from an upland river bed and was passed through a 2.36-mm sieve and retained on 63-µm sieve while the coarse aggregate was crushed granite with 12-mm maximum grain size. Laterite fines, reddish in colour, absorbent and non-granular, was obtained from Arepo area of Ogun State. The cement was ordinary Portland cement with properties conforming to British standard BS 12 [11] and with average bulk density in the range of 3050-3150 kg/m^3. The water used was clean, potable water, free from impurities. The dry densities of the constituent materials were determined in the laboratory. The test samples of the sharp sand, laterite and granite chips were obtained in accordance with BS1377-1 [12] and tests whose results are reported in this investigation were carried out in accordance with BS1377-2 [13]. The test samples were air-dried and particle size distribution analyses of the aggregates carried out. The test sieve openings used for the particle size distribution analysis for sand and laterite samples ranged from 63 micron to 3.2 mm while for the granite chippings they ranged between 2.0-19.0 mm.

The coefficient of uniformity (C_u) and coefficient of curvature (C_c), which are used to standardise gradation criteria for the sand, laterite and granite, are obtained from the relationships $C_u = (D_{60}/D_{10})$ and $C_c = ((D_{30})^2/(D_{60} * D_{10}))$ where D_{60}, D_{30} and D_{10} = diameter (mm) of the 60%, 30% and 10% passing size respectively [14].

The liquid limit (LL) of a soil sample, which is a measure of the level of water content at which the soil changes from plastic to liquid, was determined by the cone penetrometre method [15] based on the measurement of penetration of a standardised cone of specific mass into the soil from which material retained on a 425-µm test sieve has been removed. Also, the plastic limit (PL), which shows the level of water content at which the soil whose material retained on a 425-µm test sieve has been removed starts to exhibit plastic behaviour, was determined by the 'soil snake test' [15].

The plasticity index (PI), a measure of the plasticity of the soil samples, was determined for both the sand and laterite. This index indicates the water content at which the soil specimens exhibit plastic properties. The plasticity index is the difference between the liquid limit and the plastic limit, i.e. $PI = LL - PL$.

The slump test [16] was carried out on the fresh concrete test specimens to determine the consistency. The mould for the slump test measures 305 mm in height. The base diameter is 203 mm while the smaller opening at the top is 102 mm. The slump cone is filled in three layers with tamping between each filling to remove voids. The concrete is levelled off at the top of the cone. With the cone removed, the height of the slump is then measured.

The concrete mix proportion of 2:3:6 (cement: fine aggregate: coarse aggregate) by weight with a water/cement ratio of 0.65 was adopted throughout the experiment with the fine aggregate being a mixture of laterite fines and/or sharp river sand. The percentage of laterite in the fine aggregate was varied between 0-100% at 25% interval. The normal concrete specimens, i.e. without laterite, served as control for the experiment. A total of 120 150-mm-cube specimens were cast, cured and tested. The preparation and curing of the specimens were in accordance with British Standard BS1881 [16-17]. The specimens were demoulded $24 \pm \frac{1}{2}$ hours after casting and stored in a curing tank

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containing clean water until testing. After 7 and 28 days of curing, the cube strength was determined on a 600 kN Avery Denison universal testing machine using a loading rate of 120 kN/min.

At each curing age, the cubes were removed from the curing tank. The average weight and density of three cubes for each age were initially determined and the specimens were left for 2 hours before testing. This was followed by the crushing test of the specimens without heating for compressive strength determination. For each mix proportion, 3 cubes were subsequently subjected to heating for one hour at 250, 500 or 750^{o}C in a carbolite furnace with regulated temperature up to 1000^{o}C, and allowed to cool in air for 24 hours before testing.

Results and Discussion

Preliminary tests

The preliminary testing of the concrete constituent materials showed that the coarse aggregate ranged in particle sizes between 3.12-12.7 mm, had a dry density of 2930 kg/m^3, a uniformity coefficient of 2.18 and a coefficient of curvature of 1.23. The dry density of the sieved sand was 2683 kg/m^3 with a uniformity coefficient of 1.81. The laterite fines also had the same particle sizes as those of the sand but with a dry density of 2550 kg/m^3 and a uniformity coefficient of 2.0. The coefficients of curvature were 1.09 and 0.90 for sand and laterite respectively. The grading curves of the aggregates are shown in Figure 1. The moisture content of the lateritic soil, sharp sand and granite was 13.61, 6.14 and 0.6% respectively. The liquid limit of the laterite was 54.0% while the plastic limit was 21.8% and the plasticity index was 32.2%.

The average density of the plain concrete specimens was 2473 kg/m^3 while for the laterised concrete the value varied in the range of 1896-2459 kg/m^3 depending on the laterite content and the elevated temperature. Generally, a trend of significant decrease in weight and density of the test specimens with higher laterite content and temperature was observed. This confirms the findings of Balogun [18] who reported the average densities of laterised concrete specimens in the range of 1980-2540 kg/m^3. However, the reduction in density of the test specimens as the temperature increases which averages above 15% cannot be classified as insignificant. From the slump test results the mix without laterite (i.e. normal concrete) had the highest workability value of 65 mm. With the incorporation of laterite fines in the mix, the value decreased. This might be due to the finer particle sizes associated with laterite fines.

Colouration and deterioration of concrete specimens

At room temperature, the initial colour of the normal concrete cubes was grey while that of the laterised concrete cubes was reddish due to the colour of the incorporated laterite fines. Up to 250^{o}C, the colour of the test specimens did not change. However, as the temperature increased from 250 to 500^{o}C, the colour of the normal specimens changed from grey to pinkish brown while that of the laterised specimens changed from reddish to dark brown. In the 500-750^{o}C temperature range, the colour of the normal specimens changed from pinkish brown to dark brown while that of the laterised

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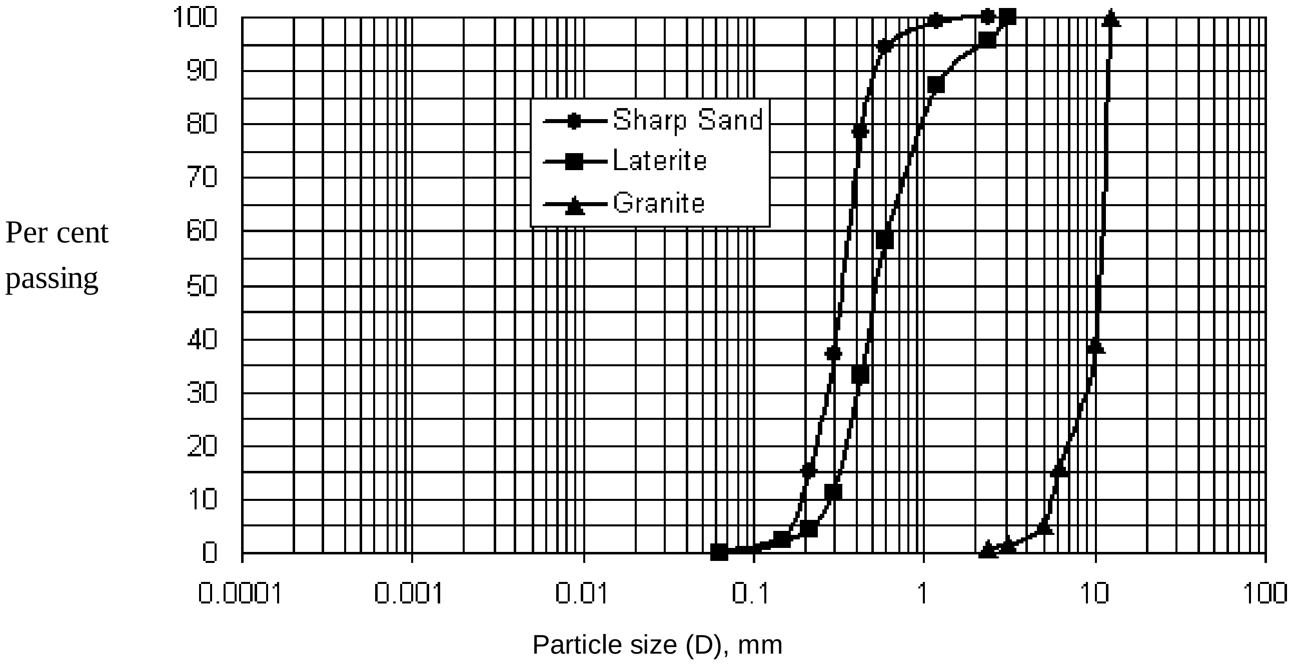

Figure 1. Particle size distribution of the aggregates

specimens changed from dark brown to a very dark brown. This might be due to the effect of heat on the iron oxide content in the laterite. The normal cubes started showing minor signs of cracking and spalling on the exposed surface at temperature between 400 and 600^{o}C. This is in agreement with the observation made by Salau [9]. In the case of laterised concrete, minor cracking and spalling occurred above 750^{o}C.

Effect of temperature on weight and density of test specimens

The variation of specimen weight with temperature for various values of laterite content is shown in Table 1 and Figure 2. For all specimens (i.e. normal and laterised) the weight decreases with increase in temperature. At 7 days of curing, the weight generally decreased with higher laterite content except for the specimens subjected to 750^{o}C heat. At ambient temperature (21^o±0.5^{o}C), the weight of normal concrete decreased from 8.3-8.4 kg to 7.8-7.9 kg for concrete with 100% laterite fines as aggregate indicating a weight loss of about 6 % due mainly to the density effect..

Maximum loss in weight of 16.7-18.1% was recorded for normal concrete subjected to 750 ^{o}C heat at 28- and 7-day curing ages respectively when compared with weight of concrete at room temperature. Specimens with 25-100% laterite fines recorded a reduction in weight varying between 14.4-5.1% and 14.6-5.1% and for 28- and 7-day curing ages respectively. The greater reduction in weight for normal concrete should be due to the near-total loss of water at higher temperature from all the voids while lateritic clay, having finer particles and lower density than sand, seems to exhibit the capacity to retain more moisture in its structure under the same condition [2].

Table 1. Average weights of specimens (kg) after heating at different temperatures

% Laterite in fine aggregate	21 ± 0.5°C		250°C		500°C		750°C	
	7-Day curing	28-Day curing	7-Day curing	28-Day curing	7-Day curing	28-Day curing	7-Day curing	28-Day during
0	8.3	8.4	8.0	7.7	7.6	7.3	6.8	7.0
25	8.2	8.3	7.8	8.0	7.3	7.7	7.0	7.1
50	8.1	8.1	7.8	8.0	7.3	7.7	7.0	7.1
75	7.9	8.0	7.6	7.8	7.4	7.4	6.4	7.2
100	7.8	7.9	7.7	7.8	7.5	7.7	7.4	7.5

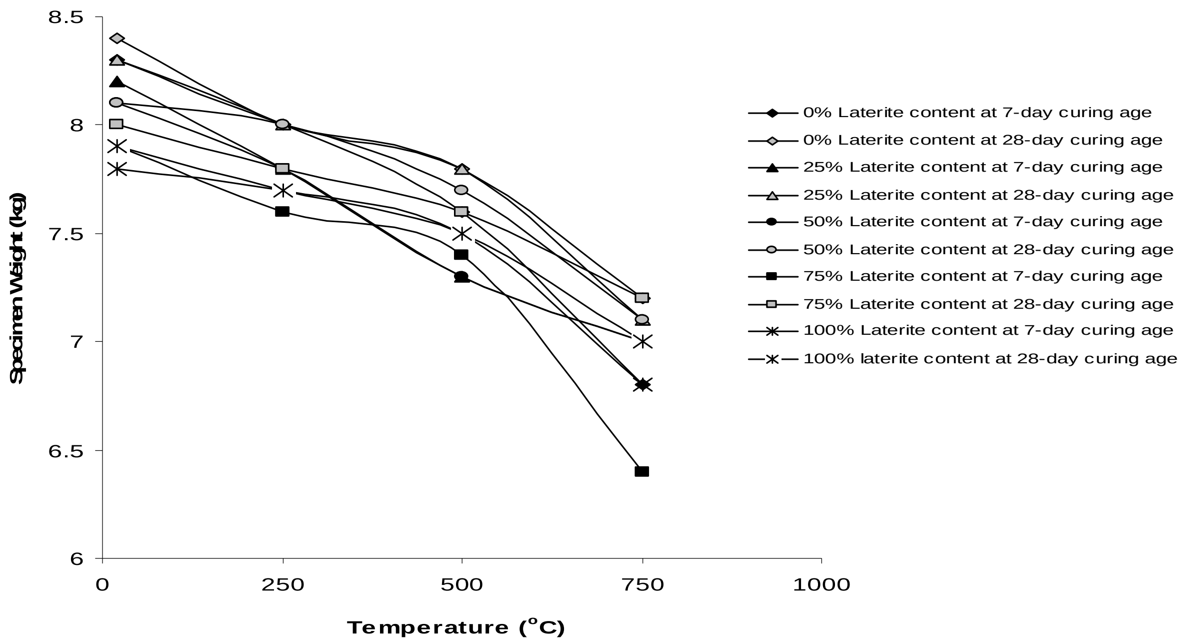

Figure 2. Variation of specimen weight with temperature for various values of laterite content at 7 and 28 days

From the above results, it can also be seen that beyond 500°C the weight loss is highest in normal concrete cubes. This could stem from the fact that normal concrete continues to chip with cracking and spalling at an average temperature of 450°C as reported by Salau [9]. This shows that the inclusion of laterite fines seems to reduce the negative effect of temperature on concrete.

Compressive strength at varying temperature

Table 2 and Figure 3 show the variation of compressive strength with temperature for the test concrete cubes with various levels of laterite content. It can be seen that for all concrete specimens (normal and laterised) the compressive strength increases with temperature up to 250°C. However, beyond 250°C compressive strength of normal concrete (at 750°C) decreases to about 50% of the room temperature values. For concrete with 25-75% laterite content the strength continues to increase

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appreciably up to 500°C, then decreases. However, the decrease is not appreciable for specimens containing 50% or more of laterite. It is also apparent that concrete with 25% laterite fines can still function well with increased load-bearing capacity when subjected to heat not exceeding 500°C for one hour. The maximum compressive strength of the test specimens is also achieved with 25% laterite content at about 500°C test temperature for both 7- and 28-day-cured specimens. Generally, the improved crushing load and compressive strength characteristics of test specimens when heated up to 500°C may be attributed to improved bonding between the constituent materials as a result of the heating process.

Table 2. Average compressive strength (N/mm^2) of concrete specimens with different percentages of laterite

% Laterite in fine aggregate	21° ± 0.5°C		250°C		500°C		750°C	
	7-Day curing	28-Day curing	7-Day curing	28-Day curing	7-Day curing	28-Day curing	7-Day curing	28-Day curing
0	19.15	20.44	24.71	26.76	19.64	20.27	9.11	10.58
25	21.87	23.02	25.42	28.36	28.67	30.44	11.64	13.69
50	20.53	21.96	23.02	24.13	24.00	25.11	12.00	18.76
75	19.20	20.36	21.16	21.87	22.04	22.27	16.49	19.29
100	14.13	16.53	18.98	19.20	19.56	20.80	20.53	21.96

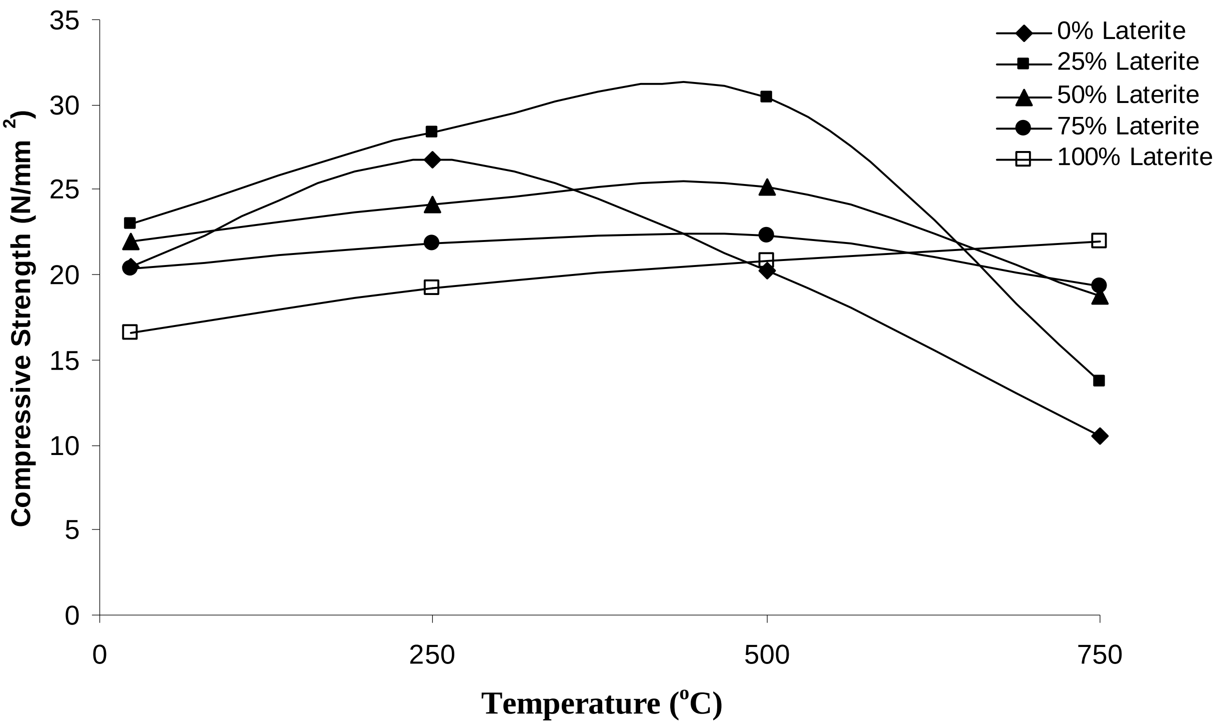

Figure 3. Variation of compressive strength with temperature for concrete of 28-day curing age with different levels of laterite content

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Conclusions

Laterised concrete can be classified as normal-weight concrete as the density of all test specimens of 28-day curing age exceeds 2000 kg/m^3 based on the cube weight of not less than 7.0 kg even at 750^{o}C.

The compressive strength of normal concrete increases with temperature up to 250^{o}C. However, concrete with 25% laterite in the fine aggregate can withstand heat up to 500^{o}C with increased compressive strength, which is about 30 N/mm2. There is no appreciable difference in strength of specimens of the two different ages when subjected to high temperatures.

From the results of the investigation, it is recommended that concrete with 25% laterite fines can be used in structural components to withstand temperature variation up to 500^{o}C. There should be a considerable economic saving if laterised concrete is used in areas of high temperature up to 500^{o}C. In such situation the application of abundant and locally available laterite is ideal as a construction material.

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