Journal of Engineering Science and Technology
Vol. 5, No. 4 (2010) 379 - 390

BEHAVIOUR OF LIGHTWEIGHT CONCRETE CONTAINING PERIWINKLE SHELLS AT ELEVATED TEMPERATURE

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Abstract

This study presents the results of the investigation of the response of lightweight concrete to elevated temperature. Available literature indicates that research works have not been carried out in this area. The variables are: mix proportion, water/cement ratio, curing age and temperature. The parameters that were measured are: compressive strength, density and bond characteristics of the concrete matrix. The results showed that the compressive strength of concrete decreased with increase in water/cement ratio and temperature but increased with increase in curing age and cement content while the density decreased with increase in temperature. The bond between the concrete matrix also decreased as the temperature increased. Lightweight concrete containing periwinkle shells is only suitable for structures that will be subjected to temperature less than 300^{o}C.

Keywords: Compressive strength, Concretes cubes, Periwinkle shells, Elevated temperature, Lightweight concrete.

1. Introduction

Attempts have been made by researchers Balogun [1] and Salau [2] to investigate the heat resistance of normal concrete that contains other aggregates such as laterite and basalt. However, none of the research works investigated the heat resistant of concrete with periwinkle shells as aggregate. The strength characteristics of concrete containing periwinkle shells have been indicated as adequate for construction works [3].

Normal concrete is widely used for construction works including buildings and could accidentally be exposed to effects of fire/heat anytime. Likewise, light-

Nomenclatures

A	Cross sectional area, mm^2
f_{cs}	Crushing strength, N/mm^2
P	Crushing load, N
w/c	Water/cement ratio

weight concrete containing periwinkle shells as aggregate can also be exposed to temperature variations due to fire/heat during its life time expectancy. The types of failure expected in concrete exposed to high temperature variation include cracking, spalling of the concrete, reduction in strength as well as partial or total disintegration of the concrete.

In developing countries like Nigeria, the high costs of procuring concrete materials for construction works have over the years constrained the users to compromise quality. This has resulted in poor performance of infrastructure in service; a major factor that has contributed to the increase in maintenance costs and the series of collapsed structures with attendant loss of lives and properties.

In the riverine areas of Nigeria, especially in the Niger Delta, lack of adequate coarse aggregate in the immediate vicinity necessitates the importation (sourcing) of this aggregate from other areas over long haulage distances. This increases the overall construction costs; hence, the need to source suitable and more readily available alternative construction materials.

Osayemwen [4] studied the use of periwinkle shells as alternative material to granite chips as coarse aggregate in concrete and concluded that the use of periwinkle shells for concrete would result in low cost housing delivery especially in the riverine areas where they are found as waste. In his research work on the characteristic of lightweight concrete made with periwinkle and palm kernel shells as aggregates in concrete for lintel beams. Beredugo [3] observed that periwinkle shells generally have poor physical and mechanical properties when used as lightweight aggregates. As aggregate, periwinkle was described as a single sized aggregate with a shape factor of 0.3 (max. diameter/length). The resultant lightweight concrete has density range of 1923-2050 kg/m^3. Ogunsanmi [5] reported that there was a reduction in the strength of concrete made with periwinkle shells when compared with conventional concrete. Also, Balogun [1] in his research on periwinkle and palm kernel shells as coarse aggregates in concrete concluded that the compressive strength of lightweight concrete produced is approximately 50% that of the conventional concrete. Orangun [6] in his exploratory investigation on the suitability of periwinkle shells as coarse aggregates reported that the strengths of concrete made with periwinkle shells were limited by the strength of the shells but high enough for structural concrete as different concrete mixes with periwinkle shells investigated resulted in compressive strength in excess of 15.0 N/mm^2. He concluded that the modulus of rupture is low compared with normal gravel concrete while the strength of reinforced members in direct compression is low, flexural members have satisfactory strength but with larger deformation than normal gravel concrete.

Falade [7] also carried out investigation on the use of periwinkle shells (PWS) partially or wholly in concrete. Mixed design concept was used for concrete containing 100% periwinkle shells. The results of the investigation showed that the workability of the concrete batches, density, compressive and flexural strengths of specimens tested decreased with increase in the proportion of periwinkle shells to granite in the mixes. Osarenmwinda et al. [8] investigated the potential of periwinkle shell as coarse aggregate for concrete. The results showed that concretes produced with 1:1:2, 1:2:3 and 1:2:4 mixes indicated compressive strengths of 25.67 N/mm^2, 19.50 N/mm^2 and 19.83 N/mm^2 at 28 days curing age respectively. These strength values met the ASTM-77 recommended minimum strength of 17 N/mm^2 for structural light weight concrete while the mixes with compressive strengths of 14.00 N/mm^2 and 16.50 N/mm^2 respectively did not meet the standard values.

The objectives of this study are to: (i) determine the effects of elevated temperatures on lightweight concrete containing periwinkle shells as coarse aggregate; (ii) assess the bond characteristics of the components of this concrete with increase in temperature and (iii) assess the effects of elevated temperature on the components of lightweight concrete.

2. Experimental Procedure

The fine aggregate (sharp sand) used was obtained from the river bed and the particles were those passing through sieve with aperture 4.75 mm and retained on sieve with aperture 0.063 mm. The fine aggregate has a density of 2550 kg/m^3 and was free from clay/silt. The coarse aggregate used in this experiment was periwinkle shells (Fig. 1), which were obtained from stockpiles at Ilaje in Lagos metropolis.

a) Deposit **b) View**

Fig. 1. Periwinkle Shells.

They were washed to remove dirts that could impair the strength if allowed in the concrete matrix; and were allowed to dry under ambient condition for ten (10) days before use in concrete mixes. The cement is Ordinary Portland cement whose properties conform to British Standard BS12 [9]. The dry densities of the constituent materials were determined in the laboratory.

The particle size analysis was carried out on the samples of the air-dried aggregates. Two mix proportions of 1:2:2 and 1:2½:2 with *w*/*c* ratio of 0.6 and 0.8 were used. For the concrete made using 1:2:2 mix proportions with *w*/*c* ratio of 0.6 and 0.8, the slump values were 0.5 and 1.5 mm respectively; while for the

1:2½:2 mix, the slump values of 0.2 and 1.1 mm were recorded for 0.6 and 0.8 *w*/*c* ratio respectively.

A total of four hundred and thirty-two (432) 150 mm concrete cubes were cast. They were de-moulded after 24±½ hours. The specimens were cured in a curing tank containing clean water until the age of test. A set of 144 concrete cubes were cured for each curing age of 7, 21 and 90 days respectively [10].

At each curing age, the cubes were removed from the curing tank and left for two (2) hours before testing. The average weight and density of three cubes for each age were determined and noted. This was followed by the crushing test to determine the compressive strengths of the test specimens at ambient temperature using 600 kN Avery Denison Universal Testing Machine (UTM) (Fig. 2) at a loading rate of 120 kN/min.

Concrete cube specimens were subsequently subjected to heating between 50°C/hr and 800°C/hr in carbolite furnace oven with regulated temperature up to 1000°C. At different levels of heating, three (3) concrete cube specimens were weighed; and the average weight and densities determined. The specimens were subsequently tested on compression testing machine. The average maximum crushing load at which the group of three cubes failed in compression was determined and used for the calculation of the compressive strength using the relationship:

$$f_{cs} = P/A$$

where f_{cs} - crushing strength, P- crushing load and A- cross-sectional area.

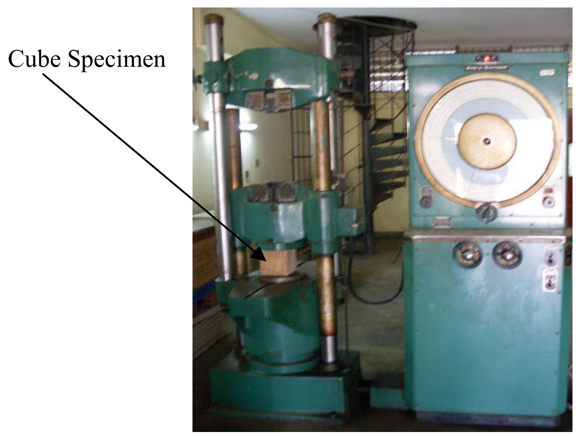
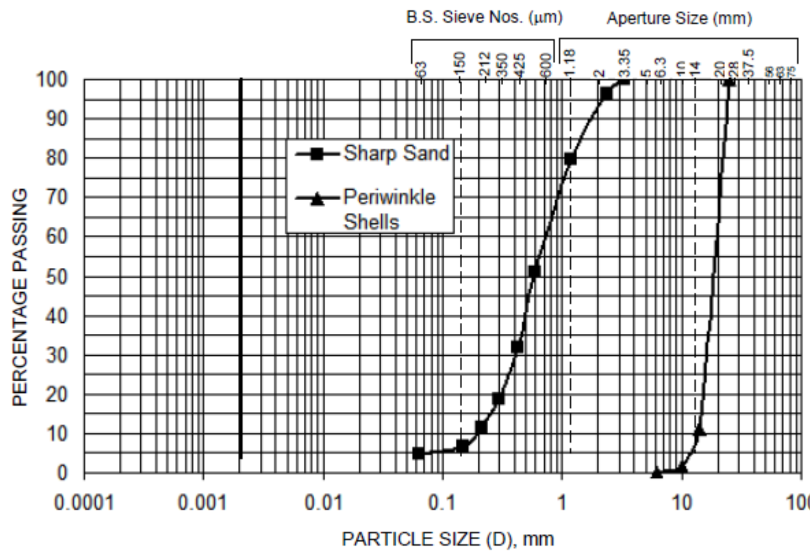


Fig. 2. A Specimen on 600 kN Avery Denison Universal Testing Machine.

3. Results and Discussion

The results of the sieve analysis on the fine and coarse aggregates are shown in Fig. 3. The results showed that the particle sizes of the coarse aggregates (periwinkle shells) ranged from 6.30 to 25.0 mm maximum size with dry density of 1353 kg/m^3. A total of 89.42% by weight of the periwinkle shells were retained on 14.0 mm sieve while 10.58% were retained on 10.0 mm sieve.

The particle sizes of the sand are those passing sieve with aperture 3.35 mm but retained on sieve of 63 μm apertures and having dry density of 2550 kg/m^3. From the particle size distribution graph, the coefficients of uniformity of the sharp sand and periwinkle shell were found to be 3.5 and 1.54 respectively, while their coefficients of curvature were 1.14 and 0.87 respectively [11].



CLAY	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	COBBLES
	SILT			SAND			GRAVEL			

Fig. 3. Particle Size Distribution of the Aggregates (Sieve Analysis).

3.1. Deterioration of periwinkle shells

No significant difference in physical appearance was observed at temperature below 300°C. The concrete started showing minor signs of cracking and spalling on the exposed surface at temperature between 300°C and 400°C. Between 400°C and 600°C, major cracks were noticed on the specimens. Between 700°C and 800°C, apart from the appearance of major cracks, smoke emitted from the samples. Due to high volume of smoke that was emitted at 800°C, heating was terminated to avoid fire or explosion of the cube specimens in the oven. At that temperature, it was noticed that the colour of the periwinkle shells changed from black to brownish. There was no noticeable colour change of the shells at lower temperature.

3.2. Density of the test specimens

Table 1 shows details of average densities of unheated test specimens with associated parameters. It was observed that at 7- day curing age, the mean density values of the unheated concrete specimens with 1:2:2 mix and *w*/*c* ratios of 0.6 and 0.8 were 1503.70 kg/m^3 and 1427.14 kg/m^3 respectively.

At 21-day curing, the average densities of specimens with *w/c* ratio of 0.6 and 0.8 were 1544.90 and 1529.62 kg/m^3 respectively; indicating a reduction in average density of 1.0% between the average densities of specimens with *w/c* ratio of 0.6 and 0.8. At 90-day curing age, concrete produced using 1:2:2 mix and water/cement ratio of 0.6 showed an average density of 1733.33 kg/m^3 while for 1:2:2 mix and at 0.8 water/cement ratio, the average density was 1585.17 kg/m^3.

Table 1. Mean Densities of Unheated Test Specimens (kg/m^3).

	***w/c* Ratio**	**Mix Ratio 1:2:2**			**1:2.5:2**		
Curing Age (days)		**7**	**21**	**90**	**7**	**21**	**90**
Density	**0.6**	1503.70	1544.90	1733.33	1540.74	1730.37	1821.73
(kg/m^3)	**0.8**	1427.14	1529.62	1579.26	1484.45	1671.60	1784.71

This shows a reduction of 8.55% in the average density of mix with 0.6 *w/c* ratio when compared with the mix with 0.8 *w/c* ratio. This same trend of decrease in values of densities was observed for the 1:2½:2 mix proportions with *w/c* ratio of 0.6 and 0.8. At 7-, 21- and 90-day curing ages, the average reduction in density values between the mixes with *w/c* = 0.6 and *w/c* = 0.8 were 3.65, 3.40 and 2.03% respectively. It was generally observed that for all test cases, the average densities of test specimens with 1:2½:2 mix were slightly higher than average densities of specimens with 1:2:2 mix. At 7-day curing age, the densities of 1:2½:2 mix proportions when compared to the density values of 1:2:2 mixes were slightly higher by 2.46 and 4.02% for mix proportions with *w/c* ratio of 0.6 and 0.8 respectively. This same trend in average density increase was observed at 21- and 90-day curing ages for mix proportions with *w/c* ratio of 0.6 and 0.8 respectively.

Table 2 shows details of densities of heated test specimens. It is observed that at 7-day curing age, the density of the heated concrete specimens with 1:2:2 mix and *w/c* ratio of 0.6 ranged between 1481.48 kg/m^3 at 0^{o}C and 1134.81 kg/m^3 at 800^{o}C while for the same mix but with *w/c* ratio of 0.8, the density ranged from 1422.22 kg/m^3 to 1078.52 kg/m^3 at 0^{o}C and 800^{o}C respectively. These show reductions in density values of 23.40 and 24.17% for mixes with *w/c* = 0.6 and 0.8 respectively.

At 21- and 90-day curing ages, concrete with 1:2:2 mix and *w/c* ratio of 0.6 showed density reduction of 26.15 and 26.50% respectively; and for mix with *w/c* ratio of 0.8, the reduction in densities were 26.35 and 24.53% for 21- and 90-day curing ages respectively. This trend was also observed in all cases for the 1:2½:2 concrete mixes.

Generally, in all test cases, the 1:2½:2 mix proportions recorded higher values of density than the 1:2:2 mix proportions with the highest range of density values at 90-day curing age. The increase in density with increase in curing age may be attributed to the absorption of moisture into the hollows (cavities) in the periwinkle shells.

The results also showed that for all mixes with *w/c* ratio of 0.6, the values of densities of test specimens were more when compared with densities of specimens with 0.8 *w/c* ratio of the corresponding mixes. Generally, the densities of specimens increased with curing age. At 7-day curing age, for 1:2:2 mix with 0.6 *w/c* ratio, the mean density of specimens is 1503.70 kg/m^3 while at 90-day curing age this value increased to 1733.33 kg/m^3 for the same set of specimens. This shows a 14.15% increase at 90 day curing. For the same 1:2:2 mix but with 0.8 *w/c* ratio, at 7 day curing age, the mean density is 1427.14 kg/m^3 while at 90 day curing, 1579.26 kg/m^3 . This reflects an increase of 10.88%. This same trend of increase in density was observed for the other mix ratios. The percentage increases in density was more in the mixes with 0.6 *w/c* ratio. This may be due to greater tendencies for water absorption while in the curing tanks.

After heating, test results show significant average weight loss, hence lower values of densities. This may be due to the loss of moisture from the cavities and pores of the periwinkle shells during the heating process in the oven.

Table 2. Mean Densities of Heated Test Specimens (kg/m^3).

	***w/c* Ratio**	**Temp. (°C)**	**Mix Ratio 1:2:2**			**1:2.5:2**		
Curing Age (days)			**7**	**21**	**90**	**7**	**21**	**90**
Density (kg/m^3)	**0.6**	**21**	1481.48	1540.70	1733.33	1525.93	1724.44	1822.22
	0.8		1422.22	1540.74	1570.37	1481.48	1674.07	1777.78
	0.6	**50**	1445.93	1531.85	1715.56	1517.04	1712.59	1783.70
	0.8		1416.30	1481.48	1561.48	1428.15	1644.44	1777.78
	0.6	**100**	1407.41	1463.70	1677.04	1511.11	1697.78	1777.78
	0.8		1351.11	1437.04	1493.33	1428.15	1591.11	1733.33
	0.6	**200**	1407.41	1478.52	1647.41	1505.19	1703.70	1739.26
	0.8		1351.11	1437.04	1496.30	1407.41	1585.19	1682.96
	0.6	**300**	1437.04	1463.70	1629.63	1505.19	1638.52	1727.41
	0.8		1351.11	1437.04	1478.52	1386.67	1585.19	1600.00
	0.6	**400**	1348.15	1386.67	1573.33	1481.48	1552.59	1614.81
	0.8		1294.82	1374.82	1451.85	1339.26	1508.15	1558.52
	0.6	**500**	1285.93	1312.59	1475.66	1463.70	1534.81	1567.41
	0.8		1220.74	1309.63	1371.85	1282.96	1520.00	1537.78
	0.6	**600**	1297.78	1321.48	1472.26	1315.56	1472.59	1549.63
	0.8		1208.89	1285.93	1327.41	1265.19	1437.04	1481.48
	0.6	**700**	1134.81	1155,56	1297.78	1297.78	1428.15	1528.83
	0.8		1078.52	1134.82	1241.48	1259.26	1262.22	1442.96
	0.6	**800**	1134.81	1137.78	1274.07	1208.89	1262.22	1422.22
	0.8		1078.52	1134.82	1185.19	1154.31	1185.19	1422.22

3.3. Bonding characteristics of the components

The bond between the concrete matrixes decreased as the temperature increased. This was evident from the ease with which the components disintegrated as the temperature was raised. Notwithstanding the presence of spikes, the near smooth surface texture of the periwinkle shells reduced the key-in effect which otherwise could have enhanced the bond characteristics of the matrix. Furthermore, the increase in temperature could have resulted in the weakening or waning in strength of the shells. This in turn, may be responsible for the early occurrence of cracks and sudden disintegration of the test specimens during heating.

3.4. Compressive strength (unheated specimens)

Table 3 shows summary of average compressive strength of unheated test specimens. It is observed that at 7-day curing age, the compressive strength values of the unheated concrete specimens with 1:2:2 mix and *w*/*c* ratios of 0.6 and 0.8 were 2.85 and 2.60 N/mm^2 respectively. At 21-day curing age, average compressive strength of specimens with *w*/*c* ratio of 0.6 and 0.8 were 4.46 and 3.65 N/mm^2 respectively. At 90-day curing age, concrete with 1:2:2 mix and water/cement ratio of 0.6 showed an average compressive strength value of 4.69 N/mm^2 while for 1:2:2 mix and at 0.8 water/cement ratio, the average strength was 4.56 N/mm^2.

Table 3. Average Compressive Strength of Unheated Test Specimens (N/mm^2).

	***w*/*c* Ratio**	**Mix Ratio 1:2:2**			**1:2.5:2**		
Curing Age (days)		**7**	**21**	**90**	**7**	**21**	**90**
Compressive Strength (N/mm^2)	**0.6**	2.85	4.46	4.69	5.34	6.00	7.34
	0.8	2.60	3.95	4.56	4.88	5.62	6.52

In all test cases, the average compressive strengths of test specimens with *w*/*c* of 0.6 were higher than the corresponding values for test specimens with 0.8 *w*/*c* ratio. The decrease in strength of test specimens with *w*/*c* = 0.8 relative to test specimens prepared with *w*/*c* = 0.6 could be attributed to presence of excess moisture for hydration process in the specimens prepared with 0.8 *w*/*c* ratio.

The results of strength variation with curing age for different mixes at 21^{o}C laboratory temperature (unheated specimens) are presented in Fig. 4. The figure indicates that the test specimens for 1:2½:2 mix at *w*/*c* ratio of 0.6 have the highest compressive strength values. At 7-day curing age, the average values for compressive strength are 5.34 N/mm^2 and 4.88 N/mm^2 for 0.6 and 0.8 *w*/*c* ratios respectively. This indicates a 9.20% more than the strength of the specimens with 0.8 *w*/*c* ratio. At 90 day curing age, the strength values are 7.34 N/mm^2 and 6.52 N/mm^2 at *w*/*c* ratio of 0.6 and 0.8. this indicates a difference of 12.42% in strength values an indication that the smaller the *w*/*c* ratio value, the higher the strength of the mixes provided the mix were prepared under the same condition.

Also, for test specimens prepared from 1:2:2 mix with *w*/*c* ratio of 0.6, the average compressive strength at 7-day curing age was 2.85 N/mm^2 as against 2.60 N/mm^2 for specimens with 0.8 *w*/*c* ratio. This indicates a reduction of 8.77% of compressive strength of test specimens with 0.6 *w*/*c* ratio. This trend of decrease in strength values for mix with 0.6 *w*/*c* ratio when compared with the mix with 0.8 *w*/*c* ratio, was also observed at 21- and 90-day curing ages.

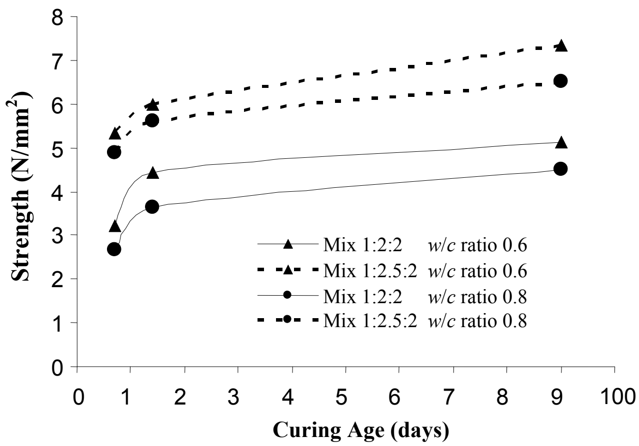


Fig. 4. Variation of Strength with Age at Ambient Temperature.

3.5. Compressive strengths (heated specimens)

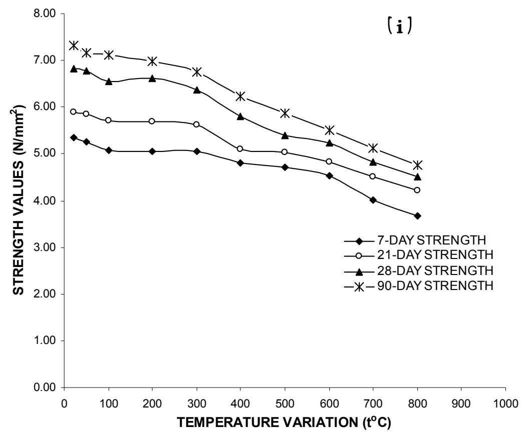
Figures 5 present results of compressive strengths with increase in temperature. It is observed that the compressive strengths of test specimens reduced with increase in temperature. At 7-day curing age, the 1:2½:2 mix test specimens cast with 0.6 *w*/*c* ratio have average compressive strength of 5.34 N/mm^2 at ambient (21^{o}C) temperature while at 800^{o}C temperature, the average compressive strength of test specimens reduced to 3.67 N/mm^2 at the same age. This shows 31.27% reduction in strength. An average of 3.48% reduction in compressive strength with every 50^{o}C increase in temperature was recorded. At 21-day curing age, between 21^{o}C and 800^{o}C temperature range, the compressive strength values are 5.90 N/mm^2 and 4.21 N/mm^2 respectively. This gives a reduction in strength values of 28.64%. An average of 3.18% reduction in compressive strength with every 50^{o}C increase in temperature was recorded.

At 90-day curing age a reduction in strength value of 35.10% corresponding to an average loss in strength of 3.9% for every 50^{o}C increase in temperature was observed. The investigation further showed that at 800^{0}C/hour, in most specimens the periwinkle shells disintegrated considerably and had all broken into pieces.

The rate of loss of strength by the test specimens was higher at the early stages of drying as the periwinkle shells tend to experience change in their structure due to temperature increase. This perceived structural change as a result of heat effect is responsible for rapid loss of compressive strength of the test specimens. As the temperature increased, the effect reached its peak, hence, the rate of influence on the compressive strength reduced.

This trend in loss of compressive strength by test specimens with increase in temperature is also observed for all other mixes as indicated in Figs. 5(ii), (iii) and (iv). In all cases, as the temperature increases, there is a gradual loss in strength of the specimens. At the temperature of 800^{o}C/hr, heated specimens lost between 26% and 40% of initial strength values before the heating process commenced.

Also, the rate of loss in strength evaluated by the slope of Figs. 5(i), (ii), (iii) and (iv) curves tends to be higher in 1:2.5:2 mixes when compared to 1:2:2 mixes, irrespective of the water/cement ratio and the curing age. The compressive strengths of the test specimens were reasonably maintained up to 300^{o}C, there after as temperature increases there is a severe and progressive decrease in strength. This is attributed to the formation of cracks in the specimens, coupled with poor bonding of the concrete matrix. The loss in strength is considerably lower before attainment of 400^{o}C temperature level, but at 600^{o}C most of the periwinkle shells (aggregate) in the test specimens were fractured. This accounts for higher strength loss at higher temperatures.



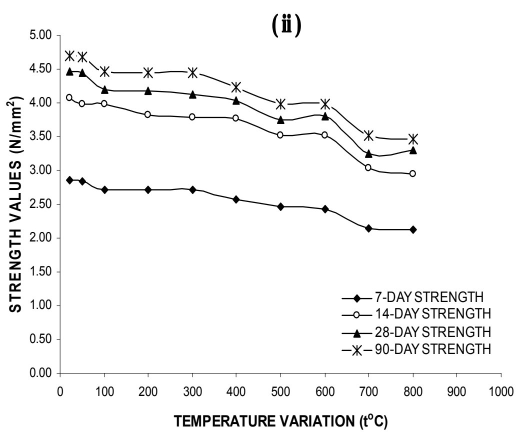


Fig. 5. Variation of Strength with Temperature for Different Mix Ratios. (i) 1:2.5:2 mix with *w/c* ratio = 0.6, (ii) 1:2:2 mix with *w/c* = 0.6,

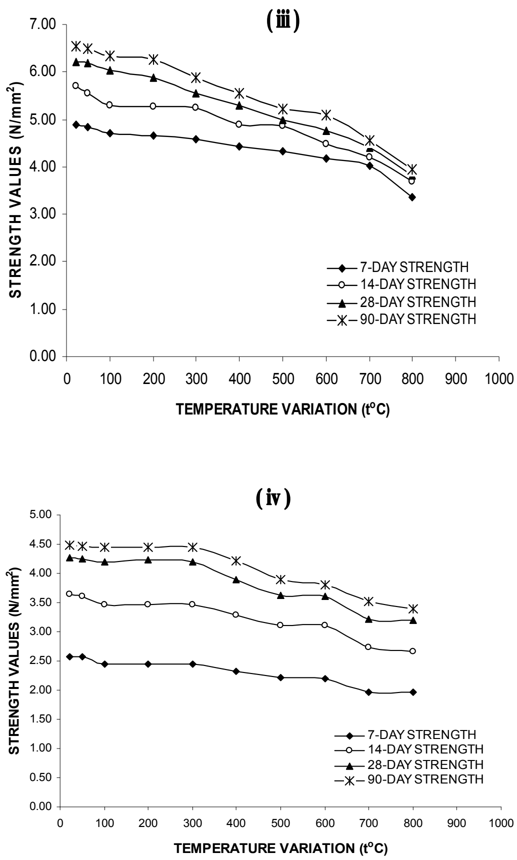


Fig. 5. Variation of Strength with Temperature for Different Mix Ratios. (iii) 1:2.5:2 mix with *w/c* ratio = 0.8, (iv) 1:2:2 mix with *w/c* = 0.8.

4. Conclusions

From the findings of this investigation, the following conclusions are made:

i. For the same concrete mix, the strength was higher for samples with lower water/cement ratio (0.6) than those with higher water/cement ratio (0.8). The observed differences varied between 4.17 and 12.91% for unheated specimens.

ii. The results showed that with increase in temperature, there was a gradual loss in strength of the test specimens. At the maximum temperature of 800°C/hr, most heated specimens lost between 24 and 40% of their strength values depending on the mix proportion and curing age.

iii. The exposure of concrete that contains periwinkle shells to elevated temperature resulted in the loss of appearance and reduction in weight.

iv. Lightweight concrete with periwinkle shells as coarse aggregates is not recommended for use in heat-resistant structures. It is recommended for use where moderate temperatures of less than 300°C are expected.

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