STRENGTH PERFORMANCE OF LATERIZED CONCRETE AT ELEVATED TEMPERATURES

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The study presents the results of an experimental program to investigate the strength performance of Laterized concrete at elevated temperature. Four concrete mixes incorporating 0, 10, 20 and 30% laterite as a replacement by weight of sand was prepared. A concrete mix ratio of 1:2:4(Cement: laterite/sand: granite) with water/cement ratio of 0.65 was used for the study. The laterite content in the fine aggregate was varied from 0 – 30% at 10% interval. Specimens cured for 7, 14, 21 and 28days were subjected to uniaxial compressive loading tests at room and elevated temperatures of 200, 400 and 600^{o}C. Results showed that for the varying percentage replacement of sand with laterite, compressive strength of laterized concrete decreases; and with increase in temperature, the strength decreases. It was also observed that an air-cooled lateritic concrete specimen has higher residual strength values than water- cooled specimens. A maximum compressive strength value of 24.10N/mm^2 was obtained for the mix with 30% laterite – 70% sand at 400^{o}C which indicates the strength of laterized concrete that is sufficient for use at elevated temperature not exceeding 400^{o}C.

Keywords: compressive strength, elevated temperature, laterite, residual strength

INTRODUCTION

The three basic necessities of life are air, food and shelter. The earth as one of the major materials was used for Man’s shelter since time immemorial (Adakole, 1992). The continuous usage of the material for affordable housing leads to its depletion hence the need to seek alternatives or develop new materials to solve the problem of housing for ever – increasing population. Basically, the use of latcon as a material in building construction involves the modification of lateritic soils in its raw form. Laterite has been used in building construction for thousands of years and presently used for shelter for approximately 30 % of the world population (confirman et al, 1990). It is formed by the weathering of rocks under humid tropical conditions and is mainly made of Iron and Aluminium hydroxides (Philip, 1993). Laterite is found extensively all over Nigeria and equally in all tropical regions of the world.

When fine aggregate is wholly or partially substituted with laterite soil in its natural form, it is known as laterized concrete or LATCON. In Nigeria, it is one of the under-utilized building materials due to the uncertainty of its strength and other properties (Ikponmwosa and Salau 2010; osadebe and Nwakonobi 2007). Lasisi and Osunade (1984) in their study on the effect of grain size on the strength of laterite cubes found that the finer the grain sizes, the higher the compressive strength. Falade (1994) took the study further when he examined the influence of water/cement ratios and mix

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proportions on workability and characteristic strength of concrete containing laterite as fine aggregate and found that water requirement increases as laterite/ cement ratio increases, for a given mix proportion.

Udoeyo et al, (2006) carried out an experimental investigation on some characteristics of concrete containing laterite as partial or full replacement of fine aggregate. Test results showed that concrete with 40% replacement of sand with laterite could attain design strength of 20N/mm^2. This fact is reinforced in the comparative study of strength properties of unreinforced and fibre reinforced normal and laterized concrete by Ikponmwosa and Falade (2006). Test results showed that strength increases with age of the test specimens. Also, laterite replacing sharp sand in concrete up to 45% produced the highest compressive strength.

Ayangade et al (2009) took the study to a new dimension when they evaluated the effects of different curing methods on the compressive strength of terracrete (Granite and laterite). Sixty cubes of 100 x 100 x 100mm using a mix of 1:1S :3, water/cement ratio of 0.62 were cast and cured using four different methods of curing for up to 35 days. Test results of the various compressive strengths of the cubes showed that out of the four curing methods, open method produced cubes with the highest compressive strength of 10.3N/mm^2 by the 35th day. Still, in the same vein to ascertain the strength properties of laterized concrete, Udoeyo et al, (2010) studied early prediction of laterized concrete strength by accelerated testing using the boiling water of accelerated strength testing to predict the 28-day compressive strength of laterized concrete; results showed that the accelerated strength of the concrete was between 72 and 84% of its twenty- eight days strength.

Lanre and Mnse (2007) advanced the investigation further when they studied the influence of weather on the performance of laterized concrete. This was achieved by conditioning laterized concrete cubes to varying temperatures and alternate wetting and drying. After curing for 28 days, the specimens were tested to determine the compressive strength. The results showed that the compressive strength of the treated laterized concrete decreases when subjected to alternate wetting and drying. The specimens conditioned to a temperature range of 75 – 125^{o}C attained compressive strength as high as 22.52N/mm^2. However, the study could not ascertain the critical failure temperatures.

When concrete is subjected to high temperatures, it is transformed due to reactions which causes progressive breakdown of its internal structure and thus experience loss in its load – bearing capacity (Bazant and Kaplan, 1996; khoury, 2000; kalifa et al, 2000; Phan et al, 2001). However, the extent of loss in LATCON load – bearing capacity was not determined and need to be ascertained. Ikponmwosa and Salau (2010) studied the effect of heat on laterized concrete. Cube specimens were cast, cured and subjected to elevated temperatures of 250, 500 and 750^{o}C. The laterite content in the fine aggregate was varied from 0 – 100% at 25% interval. Specimens cured at 7 and 28 days were subjected to uniaxial compressive loading tests at room and elevated temperatures. Tests results showed that normal concrete cannot withstand large load above 250^{o}C while laterized concrete with 25% laterite in the fine aggregate is able to resist higher load with increase in strength at higher temperatures. The peak compressive strength value of 30.44N/mm2 is recorded for the mix with 25% laterite – 75% sand at 500^{o}C.

A structural component exposed to devastating fires accidentally for long periods (exceeding fire resistance duration) resulting in high rise of temperature and reduction in strength, the reduced strength of the component is called residual strength (Kumar, 2003). The data on the residual strength of laterized concrete needs to be determined. Other changes due to high temperatures include chemical and microstructural changes, such as water migration (diffusion, drying), increased dehydration, interfacial thermal incompatibility and chemical decomposition of hardened cement paste and aggregates. These changes decrease the strength and stiffness of concrete and increase irrecoverable deformation (Zhang et al, 2000).

Many researchers have carried out investigations on the strength of plain concrete at elevated temperatures (Phan and Carino, 2000; Abramowicz and Kowalski, 2005; Chan et al, 1999; Mohamedbhai, 1983; Poon et al, 2001). The suitability of laterized concrete in the construction of structural members has been studied. However, there is dearth in research on the effect of heat on this type of concrete. Due to the plasticity and fineness of laterite fines compared to sand, the effect of temperature variation will certainly influence the strength properties of laterized concrete. It is therefore very essential that the strength performance of this concrete at elevated temperatures be understood, and that is the focus of this study.

MATERIALS AND METHODS

The study was performed at Department of building, Federal University of technology, Minna, Nigeria. Four concrete mixtures containing 0, 10, 20 and 30% replacement levels of sand by laterite were prepared with w/c ratio of 0.65 as shown in table 1.

Table 1: Mix Proportions for laterized concrete.

Mix	w/c ratio	unit weight kg/m^3				
		Water	cement	sand	laterite	granite
Mix_0	0.65	190	292	514	-	1432
Mix_{10}	0.65	190	292	462.6	51.4	1432
Mix_{20}	0.65	190	292	411.2	102.8	1432
Mix_{30}	0.65	190	292	359.8	154.2	1432

Type 1 ordinary Portland cement was used for the study with properties conforming to British standard Bs 12; 1978 with average bulk density ranging from 3050 – 3150Kg/m^3. The water used was clean, portable water, free from impurities. Two types of fine aggregates were used for the study – sand and laterite which conforms to BS 1377- 1 and 2. The sand is river sand with a specific gravity of 2.60, obtained from a deposit site at Maitumbi, Bosso local Government area, Minna, Nigeria. Laterite fines with specific gravity of 2.67, reddish- brown, absorbent and non- granular was obtained from Meikunkele, Minna, Nigeria. The coarse aggregate was crushed granite of maximum size 25mm obtained from a quarry site, Maitumbi, Minna, Nigeria. Both aggregates complied with the requirements of Bs 882. The materials including 50Kg bags of cement were transported and stored in the laboratory before use.

The coefficient of uniformity (C_u), which are used to standardize gradation criteria for the sand, laterite and granite are obtained from the relationships: $C_u = (D_{60} /D10)$ and $C_c = (D_{30})^2/D_{60} * D_{10})$ where D_{60} = diameter(mm) of the 60%, 30% and 10% passing sieve sizes respectively (Das, 2008). 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 penetrometer method (Garg, 2008) based on the measurement of penetration of a standardized 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 behavior, was determined by the soil snake test (Garg, 2008).The plasticity index (PI), a measure of the plasticity of the soil samples, was determined for the laterite sample. 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 of fresh laterized concrete mix was to determine consistency according to Bs EN 12350: Part 2 : 2000. The mould for the slump test measures 305mm in height, base diameter is 203mm, while the smaller opening at the top is 102mm. the slump cone is filled in three layers with tamping between each filling to remove voids. The concrete is leveled off at the top of the cone. With the cone removed, the height of the slump is then measured. Slump of laterized concrete against laterite content is shown in figure 3 respectively.

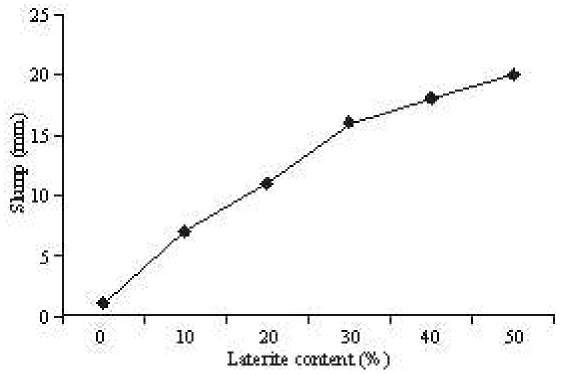

Figure 1: Slump of laterized concrete vs laterite .

The laterite content in the fine aggregate of the concrete mixtures (table 1) was varied from 0 - 30% at 10% interval. The normal concrete specimens (0% laterite) served as control for the experiment. After batching and thorough mixing of the constituents to homogeneity with a pre- calculated amount of water, the fresh mixes were cast into metallic 100mm moulds. Twenty – four test cubes were prepared from each mix. The test cubes were stripped from the moulds after 24hr, cured in a water tank for 28 days, wiped clean and then ready for testing. They were then subjected to heat pretreatment for one hour at 200, 400 and 600^{o}C in a carbolite furnace with regulated temperature up to 700^{o}C. After removal from oven, Twelve cubes from each batch were left in the laboratory to cool down naturally and another set was cooled rapidly by immersion in a water tank. These specimens were then tested for their compressive strength on a 600KN Avery Denison Universal testing machine using a loading rate of 120KN/min. Control (unheated) cubes were also crushed at room temperature (table 4 and 5).

The test used to investigate the effect of elevated temperatures on the compressive strength of laterized concrete was the residual unstressed test, where the specimens are heated without any load, cooled down to room temperature and then loaded to failure.

Table 4: Average compressive strength (N/mm^2) of concrete specimens (Air – Cooled)

% laterite in Fine Aggregate	21^o ± 0.5^{o}C (28 days)	200^{o}C (28 days)	400^{o}C (28days)	600^{o}C (28days)
0	19.67	17.60	16.60	15.15
10	17.80	16.20	15.49	14.60
20	13.67	12.58	11.56	10.39
30	12.67	10.90	10.14	9.25

Table 5: Average compressive strength (N/mm^2) of concrete specimens (water – Cooled)

% laterite in Fine Aggregate	21^o ± 0.5^{o}C (28 days)	200^{o}C (28 days)	400^{o}C (28days)	600^{o}C (28days)
0	28.76	23.58	22.15	20.11
10	29.57	23.60	21.88	20.70
20	19.67	14.75	13.97	13.38
30	18.93	13.63	13.06	12.49

This test method is shown graphically in figure 2 below.

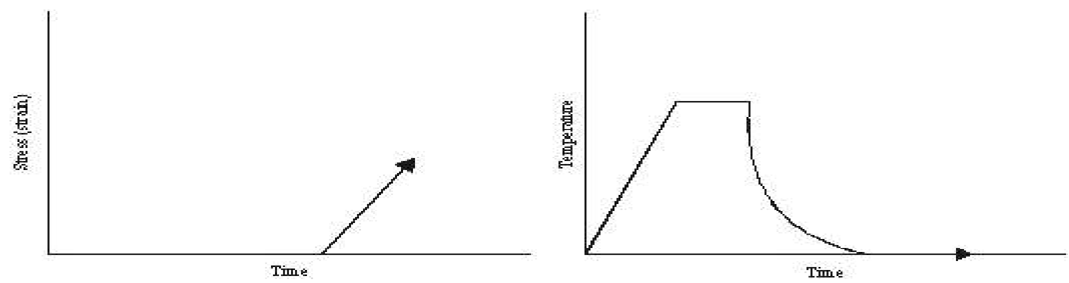

Figure 2: Residual property test method.

RESULTS AND DISCUSSION

Preliminary test results

Preliminary test results of the laterized concrete constituents are shown in table 2.

Table 2: Test results of variables for the laterized constituents.

Variable	laterized concrete constituent. Sand	laterite	coarse Agg (Granite)
Sp. Gr.	2.60	2.67	2.69
Fm	4.03	2.72	2.64
C_u	1.67	7.5	1.8
C_c	1.07	1.0	1.20
Impact value			13%
Crushed value			22.10%
Atterberg limits			
LL		20.79%	
PL		09.18%	
PI		11.61%	

The particle – size distribution of laterite and sand is shown in figure 3.

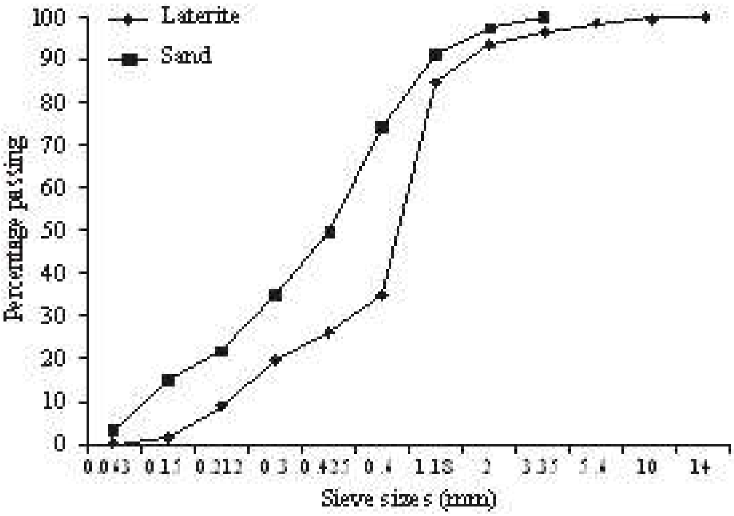

Figure 3: Grading curve for sand and laterite.

Workability

The results of the workability of fresh laterized concrete mixtures measured in terms of slump are shown in table 2 and figure 3 respectively. The workability of the concrete increases with laterite content.

Effect of elevated temperature on residual compressive strength

The test results of the residual compressive strength of plain (0% laterite content) and laterized concrete subjected to high temperatures, cooled in the laboratory freely by air (Air – cooled) and by submerging in a water-tank (water – cooled) are in tables 4 and 5 and figures 4 and 5 respectively. Figures 4 and 5 showed a common trend observed for both air – cooled and water – cooled, a decreasing residual strength with increasing temperature. The strength reduction of the tested specimens for the mixes was between 8 and 13% for air – cooled and between 18 and 28% for water- cooled, respectively at 200^{o}C. At 400^{o}C, the concrete mixes sustain greater strength losses of between 13 and 20% for air- cooled and between 23 and 31% for water- cooled.

A more severe loss in strength was observed for all the mixes at 600^{o}C. At this temperature level, the strength loss of the mixes was between 18 and 27% for the air – cooled and between 28 and 34% for water cooled.

Effect of cooling regime on residual compressive strength:

From figures 4 and 5, it is a common trend that greater strength losses were sustained by specimens cooled with water than those cooled slowly by exposure to air in the laboratory. This is in agreement with findings of other researchers who have observed that cooling concrete rapidly by immersion in water after heat pretreatment results in a thermal shock which in turn leads to lower strength values than concrete cooled freely by exposure to air after heat pretreatment (Peng et al, 2008; Yuzer et al, 2004; Chan et al, 2000).

Effect of laterite content on residual compressive strength

Figures 4 and 5 show the influence of laterite content on the residual compressive strength of specimens. At 200^{o}C heat pretreatment cooled in water Latcon specimens with 10% replacement level of sand by laterite, the compressive strength loss was about 20%; while the loss for those with 30% replacement level of sand was about 28%. Plain concrete specimens (0% laterite content) subjected to corresponding temperature had a strength loss of 18%. At 400^{o}C the strength loss of latcon with 10% replacement of sand was 13% for air – cooled and 26% for water – cooled specimens and for concrete with 30% replacement level of sand by laterite the strength loss was 31% for water – cooled and 20% for air – cooled specimen. At 600Oc the loss in the compressive strength of Latcon was observed to be severe, especially for specimen with higher laterite content. The loss in strength was between 12% for air – cooled Latcon specimens with a 10% replacement level of sand and 27% for Latcon with a 30% replacement level of sand. Plain concrete (0% laterite) subjected to 600Oc heat pretreatment had a strength loss of about 23% for air- cooled and 28% for water – cooled.

The explanation for the losses in strength by latcon with higher laterite content is similar to that given by Poon et al, (2003), for Metakaolin concrete. Possible thermal dilations in the concrete due to elevated temperatures may have resulted in large internal stresses, and ultimately, led to internal micro cracking and fracture. Besides, the dense pore structure of latcon with greater laterite clay fines could increase vapour pressure upon heating, resulting in increased cracking and severe losses in compressive strength.

CONCLUSION

The following conclusions could be drawn based on the results of this study:

When subjected to elevated temperatures between 200 and 600^{o}C the compressive strength of laterized concrete decreased in a similar manner to that of plain concrete. Though deterioration in strength for both types of concrete was severe at 600^{o}C, however, laterized concrete maintained lesser proportion of its relative residual strength than Plain concrete.

From the results of the study, the mode of cooling significantly influenced the residual compressive strength of laterized concrete. Laterized concrete specimens cooled freely by exposure to the surrounding air after heat pretreatment maintained relatively higher residual strength values than those cooled rapidly by immersing them in water.

Since findings from other studies with that contained in this study show that rapid cooling of heat pretreated specimens by immersion in water leads to severe loss in strength, other less negative alternative method(s) of rapid cooling should be investigated.

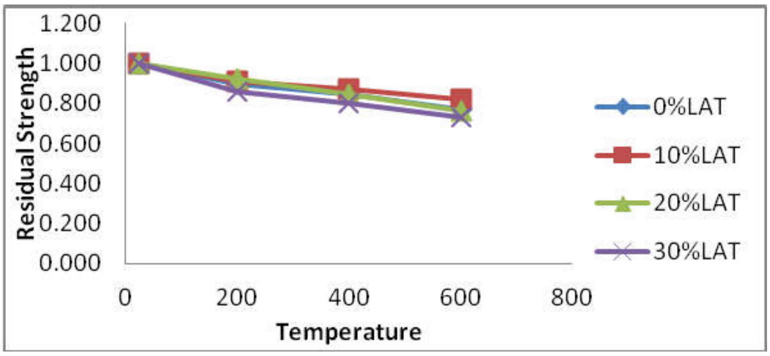

Figure 4 – Residual strength vs Temperature for Air Cooled specimens.

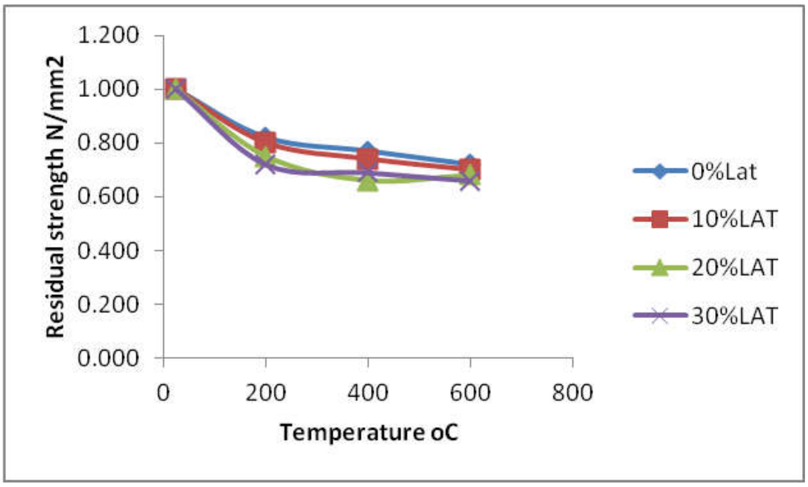

Figure 5: Residual strength vs Temperature for water – cooled samples.

REFERENCES

Adakole, J.E; Performance of mud blocks (Adobe) as masonry units. B.sc. Project, University of Jos, Jos, Nigeria, 1992.

Ayangade, J.A; Alake, O; and Wahab, A.B, The Effects of different curing methods on the

Compressive strength of Terracrete; Civil eng. Dimension, vol II, no 1, pp 41-45,2009.

Abramowicz, M and R, Kowalski, 2005. The influence of short time water- cooling on the mechanical properties of concrete heated up to high temperature. J. civ. Eng. mangt.Vol. 11, pp 85 – 90.

Bazant, Z.P and Kaplan, M.F; Concrete at high temperatures, material properties and math.

Models, Longman House, Burnt Mill, England, 1996.

Confirman, R; Agnew, N; Auiston, G; and Doehne, E; Adobe mineralogy; characterization of Adobe, from Around the world, 6th international conference on the construction of

Earthen Architecture, has Cruces, Nm, pp 14 – 19, October, 1990.

Chan, S.Y.N; G.F Peng and M. Anson; 1999. Residual strength and pore properties of high

Performance concrete; construction building materials journal, vol 14, pp261 – 266.

Das, B.M; Fundamentals of Geotechnical Engineering", International SI edn, Thompson

Learning, Toronto, 2008.

Philip, K, the Encyclopedia of the solid earth sciences, Black street scientific publication, London, 1993.

Falade, F; (1994). Influence of water/cement ratios and mix proportions on workability and Characteristic strength of concrete containing laterite fine aggregate, building and Environment, Elsevier sciences, Great Britain, pp 237 – 240.

Garg, S.K, (2008). Soil Mechanics and Foundation engineering, 6th edn, india, Delhi, Khanna Publishers.

Ikponmwosa E.E and Musbau A.S. Effect of heat on laterized concrete. Maejo international journal of science and Technology, vol. 4. No 1, 2010, pp 33 – 42.

Ikponmwosa E.E and Falade, F.A, " A study on the properties of fibre reinforced laterized

Concrete"; J. Raw Mater Res. 2006, vol 3, pp 46 – 55.

Ikponmwosa, O.F, and salau, M.A; Effect of short steel fibre reinforcement on laterized concrete

Columns. Journal of sustainable Development, vol 4, no 1; February, 2011.

Kalifa, P; Mennenteau, F.D and Quenard, D; " Spalling and pore pressure in HSC at high

Temperatures", Cement and Concrete Research, vol. 30, no 12, 2000, pp 1915-1927

Kumar, A and V. kumar: Behaviour of RC Beams after exposure to elevated temperatures,

IE journal, vol. 84, November, 2003, pp 165 – 170.

Lasisi, F; and Osunade J.A, (1984). Effect of grain size on strength of cubes made from laterite

Soils, Building and environment, pergamon press, Great Britain, pp 447-452.

Osadebe N.N and Nwakonobi T.U. Structural characteristics of laterized concrete at optimum mix proportion.Nigeria journal of Technology, Nsukka, Nigeria, vol. 26, no1, pp 12 – 17.

Oluwaseyi Lanre and Mnse, M. Asce; The influence of weather on the performance of laterized Concrete. Journal of engineering and applied sciences, vol 2,no 1, pp 129 – 135, 2007.

Phan, L.T; Lawson, J.R; and Davis, F.L; "Effects of Elevated temperature exposure on Heating Characteristics, spalling and residual properties of high performance concrete", Materials And structures, vol 34, no 236, 2001, pp 83 – 91.

Phan, L.T and carino, N.J. (2000): Fire performance of high strength concrete: research needs,

Advanced technology in structural engineering. ASCE/SEI structures congress 2000,

Proceedings, may 8 – 10, Philadelphia, PA, pp1 – 9.

Poon, C.S; S. Azhor, m, Anson and Y.L, Wong, 2001, Strength and durability recovery of fire

Damaged concrete after post – fire curing. Cement concrete composition journal, vol. 31, Pp 1307 – 1318.

Peng, G.F; S.H. Bian, Z.Q; Guo; J. Zhac; X.L Peng and Y.C Jiang. (2008) Effect of thermal Shock due to rapid cooling on residual mechanical properties of fibre concrete exposed to High temperatures, construction building materials, journal, vol. 22, no 5, pp 948 – 955.

Udoeyo, F,F, Iron, U and Odim, O.O (2006). Strength performance of laterized concrete

Construction and building materials; vol 20, no 10, pp 1057 – 1062.

Udoeyo, F.F, Robert Brooks, Philip Udo- Inyang &Richard O. Nsan, Early prediction of

Laterized concrete strength by accelerated testing. IJRRAS, vol 5, no 1, 2010.

Ukpata, J.O, Maurice E.E and Godwin A.A. Compressive strength of concrete using lateritic sand and Quarry dust

As fine aggregate. ARPN Journal of Engineering and applied Sciences, vol.7, no1, January, 2012. pp 81-92.

Yuzer, N; F. Akoz and L.D Ozturk, 2004. Compressive strength – colour change relation in

Motars at high temperature. Cement concrete Research journals, vol. 34, pp 1803 – 1807.

Zhang, B. N, Bicanic, C.J. Pearce and G. Balabanic, 2000, Assessment of toughness of concrete Subjected to elevated temperatures from complete load – displacement curve- part I;

General introduction, ACI Materials journal, vol. 97, no 5, pp 550 – 557.