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Residual Compressive Strength of Laterized Concrete Subjected to Elevated Temperatures

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Abstract: This research presents the results of an experimental program to investigate the strength performance of laterized concrete (LATCON) when subjected to elevated temperatures of 200, 400 and 600ºC. Six concrete mixes incorporating 0, 10, 20, 30, 40 and 50% Laterite as a replacement by weight of sand was prepared. After heat pretreatment specimens were cooled using either rapid cooling (water-cooling) or natural cooling (air-cooling). An analysis of variance test shows that exposure temperature, cooling regime, and their interaction have a significant influence on the compressive strength of the samples. When subjected to the investigated temperatures specimens experienced strength losses that increased with temperature. This study further reveals that air-cooled concrete specimens maintained higher residual strength values than water-cooled specimens. A comparison of the residual compressive strength data obtained in this study with code provisions in Eurocode and CEB design curve shows that these codes could be applied to LATCON subjected to temperature below 400ºC.

Key words: Compressive strength, elevated temperatures, influence, laterized concrete

INTRODUCTION

Concrete, a leading construction material in civil engineering is sometimes exposed to elevated temperatures due to natural hazard (Vodak *et al.*, 2004). Subjecting concrete to high temperatures leads to transformations and reactions that cause the progressive breakdown of cement gel structure and consequent loss in load-bearing capacity (Khoury, 1992; Anonymous, 1972; Erline *et al.*, 1972; Hanson, 1990; Handoo *et al.*, 2002). High temperatures also cause chemical and micro-structural 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). The effect of elevated temperatures at varied heating scenarios on the strength of plain concrete has been investigated by many researchers (Mohamedbhai, 1983; Khalaf and DeVenny, 2004; Chan *et al.*, 1999; Min *et al.*, 2004; Poon *et al.*, 2001; Phan *et al.*, 2001; Xiao and Falkner, 2006; Mahdy *et al.*, 2002; Abramowicz and Kowalski, 2005; Jianzhuang and Konig, 2004; Phan and Carino, 2000). However, there is dearth in research data concerning the behavior of LATCON under high temperatures. For structural safety in service, and possible rehabilitation, strengthening and reconstruction of laterized concrete in the event of fire, it is very essential that the strength properties of this concrete subjected to elevated temperature be understood, and that is the focus of for this experimental program.

MATERIALS AND METHODS

The study was performed during 2005 at the Federal University of Technology in Owerri, Imo State, Nigeria. The cement used was a Type I ordinary Portland cement, a product of the Eastern Bulkcem Company Limited, Port Harcourt, River State of Nigeria. It had a specific gravity of 3.15, a soundness value of 0.53 mm, and initial and final setting times of 50 and 120 min, respectively. Two types of fine aggregate were used for this study- sand and laterite. The sand having a specific gravity of 2.60 was obtained from the Otamiri River near the Federal University of Technology, Owerri, Imo State of Nigeria. The laterite was obtained from a borrow pit within the same region. The Scanning Electro-micrograph (SEM) showed a mixture of large and smaller particles of lateritic soil (Fig. 1). The bulk chemical composition of the lateritic soil measured using XRF are shown in Table 1. Tests for the SEM, physical and chemical properties of the Lateritic soil were conducted at EMSL Analytical in Westmont, New Jersey, U.S.A. The grain size distribution of the aggregates is shown in Fig. 2. The coarse aggregate used was a crushed granite rock with a maximum size

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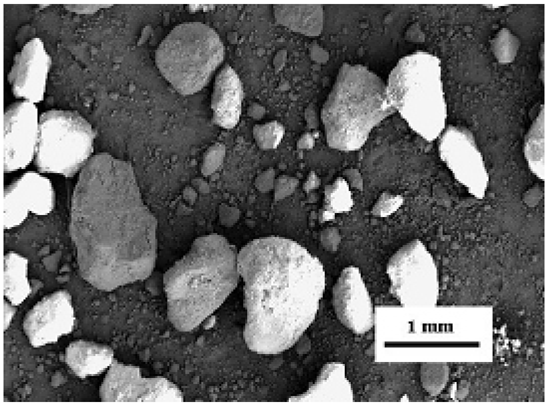

Fig. 1: SEM of lateritic soil (20X)

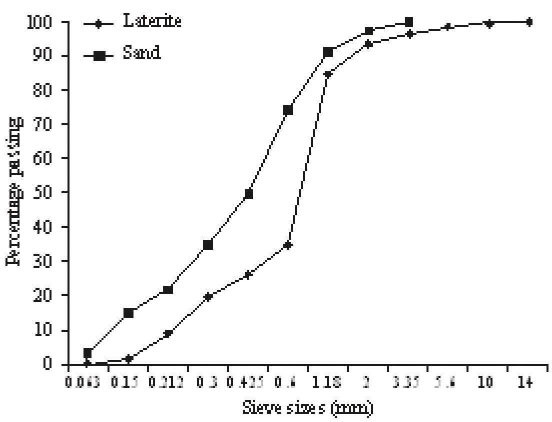

Fig. 2: Particle-size distribution of laterite and sand

Fig. 3: Blue M single-wall convection oven with variable heat controls

38 mm obtained from the Isiagu deposit in Okiwe. It had a specific gravity of 2.66, and an impact and crushing values of 13.0 and 22.10%, respectively. Water for the various mixes was as specified by BS EN 1008: 2000.

Table1.Physical and chemical properties of lateritic soil

Properties	Value
Moisturecontent(%)	0.22
Specificgravity	2.51
Lossonignition	0.93
Chemicalcomposition(%)	
SiO_2	77.80
Al_2O_3	18.40
Fe_2O_3	2.38
TiO_2	0.82
K_2O	0.13
MgO	0.13
P_2O_5	0.10
Cr2O	30.09
SO	30.09
CaO	0.04
ZrO	20.03
MnO	0.01
ZnO	0.01

Preparation of specimens and test methods: Six concrete mixtures containing 0, 10, 20, 30, 40 and 50% replacement levels of sand by laterite were prepared with w/c ratio of 0.50 as shown in Table 2. After batching and thorough mixing of the constituents to homogeneity with a pre-calculated amount of water, the fresh mixes were cast into metallic moulds of 150 mm size. Twenty-one test cubes were prepared from each mix. The test cubes were stripped from the moulds after 24 h, cured in a water tank for 21 days, wiped clean and left under laboratory conditions for 7 days before testing on the 28th day. They were then subjected to heat pretreatment for 1 h using the "Blue M Single-wall Convection Laboratory Oven" with a maximum temperature of 700ºC (Fig. 3). After removal from the oven, nine cubes from each batch were left in the laboratory to cool down naturally. Another set of nine was cooled rapidly by immersion in water. These specimens were then tested for their compressive strength using a standard motorized compression machine in accordance with BS EN 12390: Part 3: 2002. Three control (unheated) cubes were also crushed at room temperature. The test used to investigate the effect of elevated temperatures on the compressive strength of LATCON was the residual unstressed tests, where the specimens are heated without any load, cooled down to room temperature and then loaded to failure. This test method is shown graphically in Fig. 4. Slump test of fresh concrete mix was according to BS EN 12350: Part 2: 2000. Water absorption was determined using the Eq (1) shown below after weighing specimens at each replacement level of sand by laterite before and after immersion in water for 24 h.

$$\text{Water absorption (\%)} = \frac{Ws - Wo}{Wo} \times 100 \qquad (1)$$

Table 2.: Mix proportion for LATCON

Mix	W/C ratio	UnitWeight ($kg.m^{-3}$)				
		Water	Cement	Fine aggregate		Coarse aggregate
				Sand	Laterite	
ML0	0.5	185	370	646.0	0	1199
ML10	0.5	185	370	581.4	64.6	1199
ML20	0.5	185	370	516.8	129.2	1199
ML30	0.5	185	370	452.2	193.8	1199
ML40	0.5	185	370	387.6	258.4	1199
ML50	0.5	185	370	323.0	323.0	1199

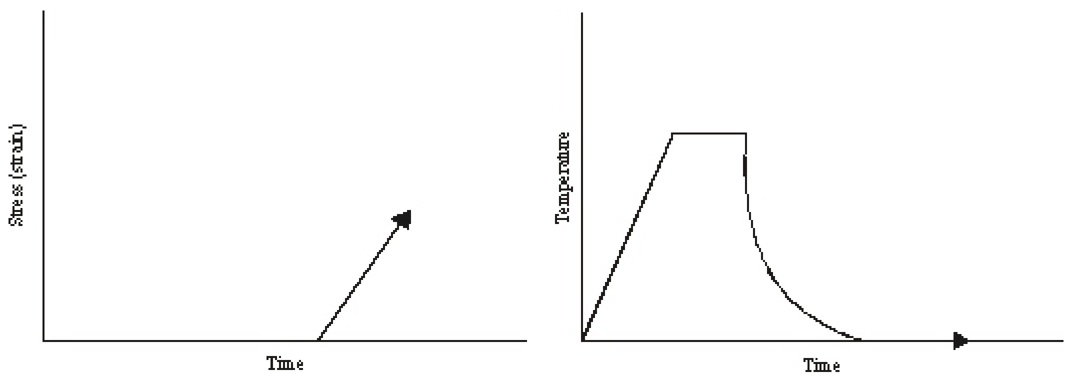

Fig.4: Residual property test method

Ws = saturated weight of sample after 24 h submersion in water
Wo = weight of sample before submersion in water

RESULTS AND DISCUSSION

Workability and water absorption: Presented in Fig. 5 are the results of the workability of freshed laterized concrete mixtures measured in terms of slump. The workability of the concrete increases with laterite content. The results of water absorption of laterized concrete in Fig. 6 show a reverse trend, i.e., decrease with increase in laterite content. The explanation for the observed trend for the water-absorption could be due to the presence of clay fines in the concrete, which increased as the laterite content increased, making the matrix more repellent to the ingress of water.

Effect of elevated temperature on residual compressive strength: Presented in Fig. 7 and 8 are the test results of the residual compressive strength of plain and laterized concrete subjected to high temperatures and cooled by either submerging in a water tank (water-cooled) or left in the laboratory to be cooled freely by air after the heat treatment (Air-cooled). As shown in the figures a common trend that was observed for both the water-cooled and air-cooled was a decreasing residual strength with increasing temperature. A one-way analysis

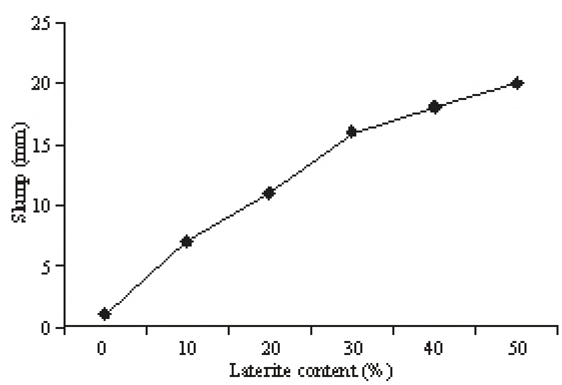

Fig. 5: Slump of Laterized Concrete vs Laterite Content

of variance tests to verify the influence of temperature variation on the observed trend presented in Table 3 show that its effect was highly significant. The calculated F-statistics at $\alpha = 0.05$ was between 1.8×10^4 and 3.95×10^4 compared to 3.98 for critical F-value. The ANOVA test further revealed that the effect of Temperature variation on the decreasing residual compressive strength of concrete was far greater than the effect of cooling regime and that of the interaction effect of temperature and cooling regime for specimens with higher content of laterite (30, 40 and 50% laterite). For instance, for specimens with 50% laterite content, the F-statistics for temperature variation (3.95×10^4) was seven times that of

Table 3: ANOVA results of residual compressive strength of LATCON and plain concrete

SV	DF	SS	MS	$F_{calculated}$	$F_{critical}$
0%Lateritecontent					
Temperature(T)	2	11.33	5.67	18900**	3.98
Cooling(C)	1	6.52	6.52	21733**	4.84
T×C	3	2.74	0.91	3033**	3.59
10%Lateritecontent					
Temperature(T)	2	9.52	4.76	15866**	3.98
Cooling(C)	1	6.80	6.80	22667**	4.84
T×C	3	2.44	0.81	2700**	3.59
20%Lateritecontent					
Temperature(T)	2	14.68	7.34	18350**	3.98
Cooling(C)	1	7.81	7.81	19525**	4.84
T×C	3	2.91	0.97	2425**	3.59
30%Lateritecontent					
Temperature(T)	2	22.91	11.46	114600**	3.98
Cooling(C)	1	10.66	10.66	106600**	4.84
T×C	3	4.03	1.34	13400**	3.59
40%Lateritecontent					
Temperature(T)	2	31.50	15.75	78750**	3.98
Cooling(C)	1	8.03	8.03	40150**	4.84
T×C	3	1.85	0.62	3100**	3.59
50%Lateritecontent					
Temperature(T)	2	23.69	11.85	39500**	3.98
Cooling(C)	1	1.62	1.62	5400**	4.84
T×C	3	1.31	0.44	1467**	3.59

SV = sourceofvariation; DF = degreeoffreedom; SS = sumofsquare; MS = meansumofsquare; VR = varianceratio; **: $p<0.001$

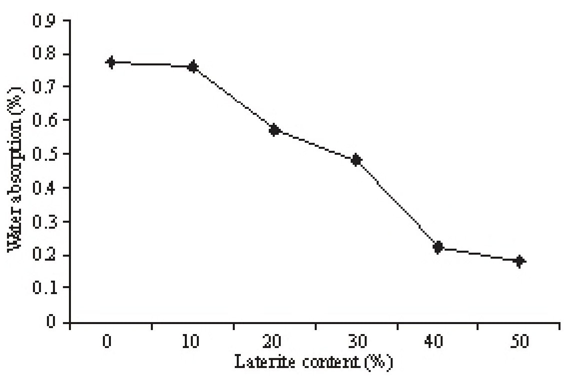

Fig. 6: Water absorption of laterized concrete vs laterite content

cooling regime (5.400×10^3), and twenty seven times that of interaction effect of temperature and cooling regime (1.467×10^3). The strength reduction of the tested specimens for the mixes was between 0.8 and 3.4% for water-cooled specimens and between zero and 1.10% for air-cooled, respectively at 200ºC. At 400ºC the concrete mixes sustained greater strength losses of between 11.0 and 17.7% for water-cooled and between 2.8 and 11.4% for the air-cooled. A more severe loss in strength was observed for all the mixes at 600ºC. At this temperature level the strength loss of the mixes was between 14.0 and 26.3% for water-cooled and between 5 and 13.4% for air-cooled.

Effect of cooling regime on residual compressive strength: The one-way analysis of variance test presented in Table 3 shows that the effect of cooling regime on the compressive strength of specimens subjected to elevated temperature is statistically significant at 5% level since the calculated values of F-statistics are higher than the corresponding critical or tabulated F-values. As shown in Fig. 7 and 8, it was 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 corroborates the 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: The influence of laterite content on the residual compressive strength of specimens is also shown in Fig. 7 and 8. For LATCON specimens with 10% replacement level of sand by laterite subjected to 200ºC heat pretreatment cooled in water, the compressive strength loss was about 2.0%, while the loss for those with 50% replacement level of sand was about 4%. Plain concrete specimens subjected to corresponding temperature had a strength loss of 0.8%. At 400ºC the strength loss of LATCON with 10% replacement level of sand was 11% for water-cooled and 3% for air-cooled specimen, and for concrete with 50% replacement level of sand by laterite the strength loss was 18% for water-cooled and 11% for air-cooled specimen. At 600ºC the loss in the compressive strength of LATCON was observed to be severe, especially for specimen with higher

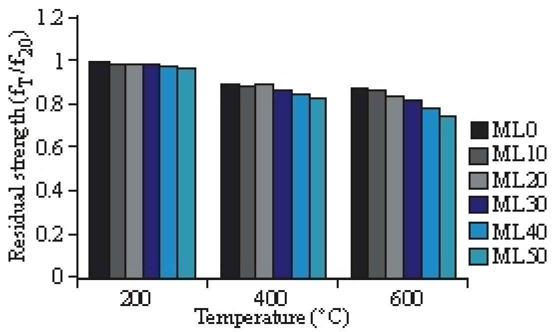

Fig.7: Residual compressive strength vs temperature for water-cooled concrete

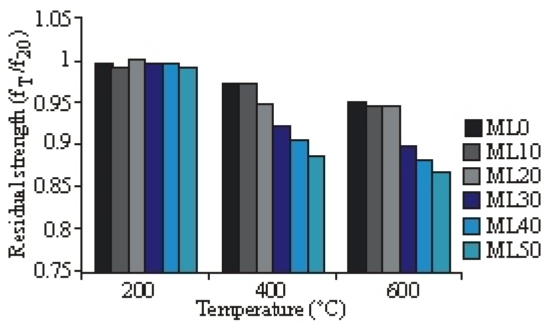

Fig.8: Residual compressive strength vs temperature for air-cooled concrete

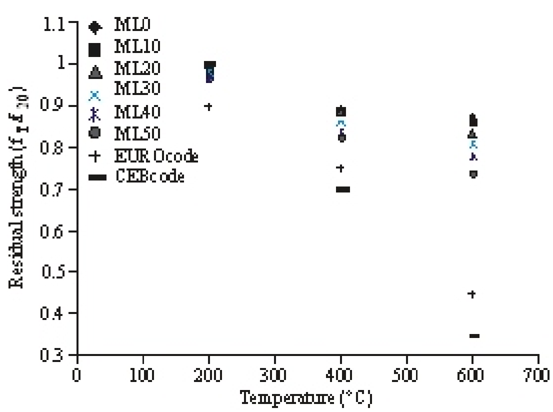

Fig.9: Comparison of eurocode and CEB design values with latcon test results within the investigated temperature range (water-cooled)

laterite content. The loss in strength was between 14% for water-cooled LATCON specimens with a 10% replacement level of sand, and 26.3% for LATCON with a 50% replacement level of sand. Plain concrete subjected to 600ºC heat pretreatment had a strength loss of about 14% for water-cooled and 5% for air-cooled. The explanation for the severe losses in strength by LATCON with higher laterite content is similar to that

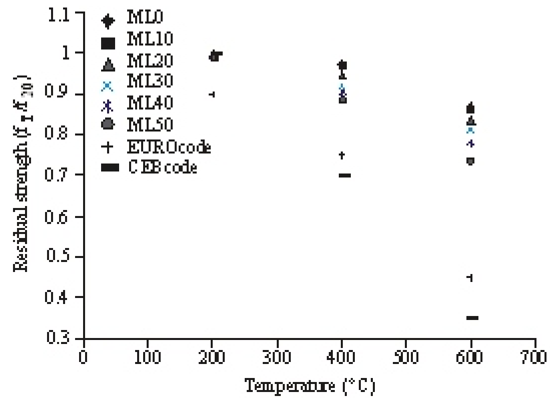

Fig.10: Comparison of eurocode and CEB design values with latcon test results within the investigated temperature range (air-cooled)

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 vapor pressure upon heating, resulting in increased cracking and severe losses in compressive strength.

Comparison of LATCON residual strength to euro and CEB code provisions for residual compressive strength of concrete subjected to elevated temperatures: At present, there is no code provision for the compressive strength of laterized concrete exposed to high temperatures. To verify the applicability of some international code for the design of LATCON against fire, the values of the residual strength obtain for the concrete in this study are plotted against the values provided in Eurocode and CEB design curves (Fig. 9 and 10). As could be seen from the plots, the code design curves are more applicable to LATCON at 200ºC than at 400 and 600ºC.

CONCLUSION

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

- The compressive strength of LATCON decreased in a similar manner to that of plain concrete when subjected to elevated temperatures between 200 and 600ºC. Deterioration in strength for both types of concrete was severe at 600ºC. However, plain concrete maintained a greater proportion of its relative residual strength than LATCON.
- The results indicate that the cooling regime also significantly influenced the residual compressive strength of LATCON. LATCON 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 this study corroborates other research findings which show that rapid cooling of heat pretreated specimens by immersion in water leads to severe loss in strength, it is suggested that other less harmful alternative methods of rapid cooling should be investigated.

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