INVESTIGATION INTO THE EFFFECTS OF CLIMATE CHANGE ON CONCRETE PROPERTIES

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Abstract

The study examined the effects of climate change orchestrated by environmental degradation and global warming on the engineering properties of concrete. The climatic parameters considered in this work were temperature and rainfall. Rainwater samples were collected from three industrial areas and one non-industrial area in Ogun State and were analysed for acidity. Test cubes cast and cured under ambient temperature in the concrete laboratory of the Federal Polytechnic, Ilaro were subjected to varying conditions of temperature and immersed in rainwater samples for 1, 2 and 3 months. The effects of these climate indicators on compressive strength, shrinkage, thermal cracking, and aesthetics of concrete were studied. The result indicated that rainwater samples from industrial areas were more acidic having significant influence on the properties of concrete. It is therefore suggested that buried and water retaining structures should be accorded adequate protection against the negative impacts of climate change during conception and design.

Keywords: *Climate change, compressive strength, global warming, concrete, acid rain*

INTRODUCTION

Climate is the weather that is dominant in a particular region for a period of not less than thirty-five years. The term includes temperature, rainfall and wind patterns. Geography, global air and sea currents, tree cover, global temperatures and other factors influence the climate of an area, which causes the local weather [Williams, 2002].

Naturally, climate does change but not noticeable except for over a long period of years. What gives one concern about the climate change is the alarming rate at which human activities influence climate pattern.

Scientific evidence that humans were changing the climate first emerged in the international public arena in 1979 at the First World Climate Conference (Depledge & Lamb, 2005). At this time when the effects of human-induced climate change were first discovered, the changes were not regarded as important or significant. However, by 1988 when the Intergovernmental Panel Climate Change (IPCC) was formed, the dangerous consequences of climate change were becoming clear (Houghton, 2007).

The major cause of climate change is the release of greenhouse gases (GHG) such as CO_2, nitrous oxides, chlorofluorocarbon, and hydrocarbons such as methane, ozone, aldehydes and water vapour into the atmosphere. Some of these gases especially CO_2 and oxides of nitrogen were dissolved in rainwater and fall to the earth as acid rain. CO_2 dissolved in water to form carbonate acid while nitrous oxides dissolve in water to form nitric acids. Because of the high level of ionization of these acids, they erode metallic surfaces and destroy biodiversity (Etiosa and Matthew, 2007). The rate at which GHGs are released into the atmosphere is escalating.

As at 1998, the Earth Trend (2003) put the global value as 24trillion metric tonnes while that of the Sub Sahara Africa was 515,001 (thousand metric tonnes) with Nigeria contributing over 15% (78,455 thousand metric tonnes). Other Non-CO_2 Air Pollutants includes Sulfur Dioxide, or SO_2, a primary contributor to acid deposition, or acid rain; Nitrogen oxides, or NOx, also contributes to acid rain and global warming. It is formed when fuel is burned at high temperatures, as in a combustion process. The primary sources of NO are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels; Carbon monoxide, or CO; Non-methane VOCs (Volatile Organic Compounds) are chemicals that vaporize at room temperature, like benzene, toluene methylene chloride and methyl Chloroform [Earth Trends, 2003].

The foremost evidence for worldwide climate change has been global warming: For Northern Hemisphere temperatures during the second half of the 20th century were higher than during any other 50-year period in the last 500 years and probably also in the last 1,300 years. In addition, eleven of the last twelve years (1995–2006) rank among the 12 warmest years in the instrumental record of global surface temperature that began in 1850 (Alley *et al.*, 2007). The rate of temperature increase has risen from 0.1° Celsius per decade over the past 100 years to 0.2° Celsius in the past decade. Climate experts predict that the average global temperature is most likely to increase further by between 1.8° and 4.0° Celsius over the course of this century, but could rise by as much as 6.4°C in the worst case. Moreover, these are just cautious estimates [European Union, 2009].

The environment is similar in many ways to a biological system. A change in any component of a biological system will cause a distortion in the entire system. The ecological system behaves in a similar way. Climate is a fundamental element of the environment and a change in climate will consequently cause a change in the entire environment, affecting other elements of the environment. Hence, climate change has the potential of affecting all natural land human systems and may be a threat to human development and survival socially, politically and economically.

Climate change is already having an impact in Europe and around the globe. Unless it is put under control, it could trigger catastrophic events. Climate change will affect all countries, but developing countries are the most vulnerable. They often depend on climate-sensitive activities such as agriculture, and do not have much money to adapt to the consequences of climate change.

High temperature, drought, rapid rising sea levels, flooding, food and water shortage, heavy rainfall (including acid rain), extreme wind (hurricanes and typhoons), Glacier and snow melt, economic costs and conflicts are some of the consequences of climate change (Stern, 2006, Williams, 2002, Alley *et al.*, 2007, La Trobe, 2002).

All the elements of the environment including building structures and infrastructure will definitely be affected by climate change. Etiosa and Mathew (2007) studied effect of climate change in Niger Delta; they reported that the Acid rains due to greenhouse effect erode roofing sheets of houses at alarming rate, that the people of the Niger Delta are forced to change their roofing sheets every now and then.

This paper presents the impact of the elements of climate change on the engineering properties of concrete. The elements considered are: acid rain and temperature.

MATERIALS AND METHODS

Study Areas

Samples of rainwater were selected from four (4) areas for the study. Of these, three are industrial areas while the fourth is non-industrial area that also served as control. The three industrial areas selected were Ewekoro, Sango and Agbara while the non-industrial area chosen was the Campus of the Federal Polytechnic (FPI), Ilaro all in Ogun State, Nigeria.

Collection of Rainwater Samples

Samples of rainwater were collected from these study areas in early May, 2010. During the collection of samples, care was taken to ensure that samples were representative of the water used and that no accidental contaminations occur during sampling. They were collected directly in clean sterilized plastic containers by placing the container on a raised platform in an open area ensuring that the water did not have contact with any object before getting into the container. The samples were then analysed for acidity to confirm the existence of climate-induced acid rain.

Test of Acidity

Since the p^H of water is taken as a measure of the degree of acidity or alkalinity. The p^H of the rainwater samples collected was determined. Ten millilitres (10mls) of water sample was put in test tubes and 20mls of bromothymol blue solution was added to each test tube, then a glass electrode was dipped into the solution and then into the p^H meter to determine the p^H of the water sample.

Effect of Acid Rain on Compressive Strength of Concrete

Materials

Binder: Elephant Portland cement produced by Lafarge (Nig.) Cement Company was used as binder. It has properties that are in accordance as specified by BS12.
Aggregate: Crushed granite with maximum nominal particle size of 20 mm was used as coarse aggregate and sand from "Odo Ogun" with uniform size distribution was used as fine aggregate. The grain size distribution curve for the sand used is shown in Figure 1. It was ensured that the aggregates were devoid of impurities.
Water: Distilled water was used for the mix to ensure that the composition of water does not contribute to the effect of the samples to be tested.

Compressive Strength Test

Concrete mix ratio used in this research was 1:2:4 with water cement ratio of 0.4 by weight. The concrete mix was put in mould of 150 ×150 × 150mm. The filling of the mould was in three layers and were manually compacted using 16mm diameter metal rod at minimum strokes of 35. The moulds were removed after 24 hours and concrete cubes were transferred into curing tank containing fresh water at room temperature for 28 days. Thereafter, concrete cubes were immersed in the samples of rainwater collected from the study areas for periods of 1, 2, and 3 months. The compressive strengths of each of the cubes at the expiry of the ages were determined and the average values computed. Physical appearance of the cubes was also assessed before and after immersion.

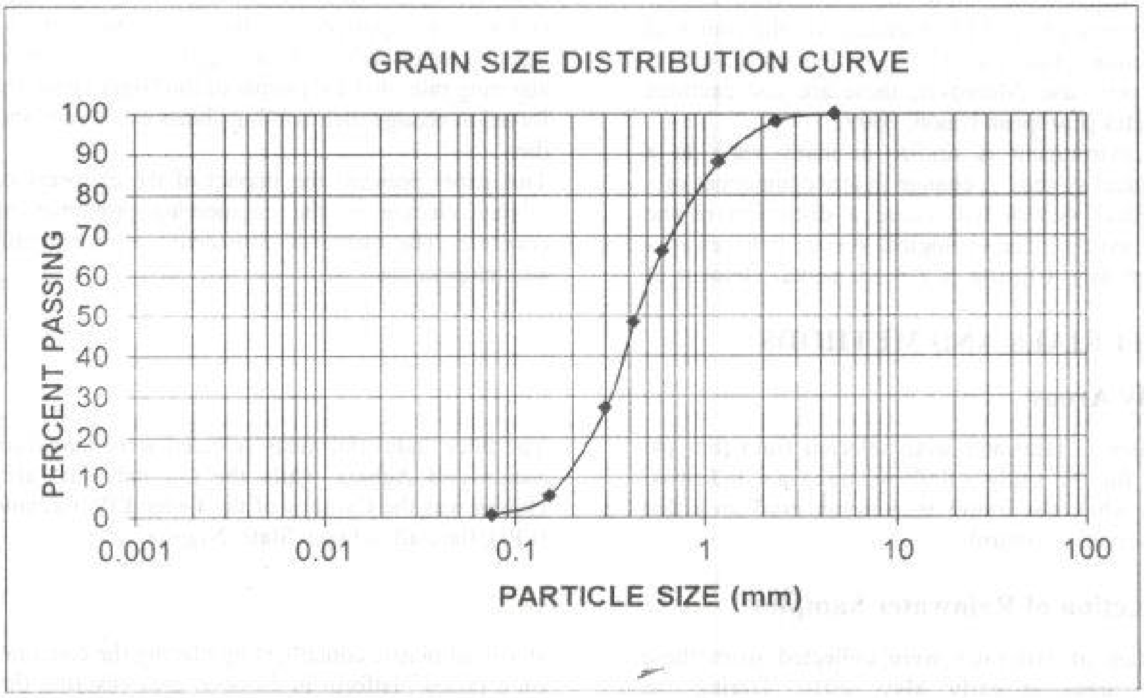

Figure 1: Grain size distribution curve for fine aggregate (sand)

Effect of Temperature Rise on Concrete Properties

The concrete cubes cured for 28 days were put in oven at different temperature of 40^{0}C, 45^{0}C, 50^{0}C, 55^{0}C and 60^{0}C for a period of 30, 60 and 90 minutes. The compressive strength of each cube was determined. In addition, drying shrinkage and crack were measured. The temperature values were carefully chosen to fall within the average and the maximum temperature ever recorded in the country. The hottest temperature ever recorded in Nigeria was in March-April 1995 where temperature rose to 55^{0}C in the North-Eastern Part of the Country; specifically Borno while Kano, Lagos, Sokoto have their highest temperature put at 43.3^{0}C, 37.2^{0}C and 47.2^{0}C (http://www.blurtit.com/q9664730.html; www.mherrera.org).

RESULTS AND DISCUSSION

p^H Value

The p^H values of the samples collected are shown in Figure 2. It is shown that the average P^H Values sample from Ewekoro, Agbara and Sango are 5.6, 6.0 and 6.3 respectively while that of the FPI campus is 6.9. These results indicate that all the rainwater samples collected from the industrial areas were acidic with pronounced acidity in the sample from Ewekoro. One major factor that could be attributed to the acidity of the water is evidently the emissions from these industrial areas that might have dissolved in the rainwater.

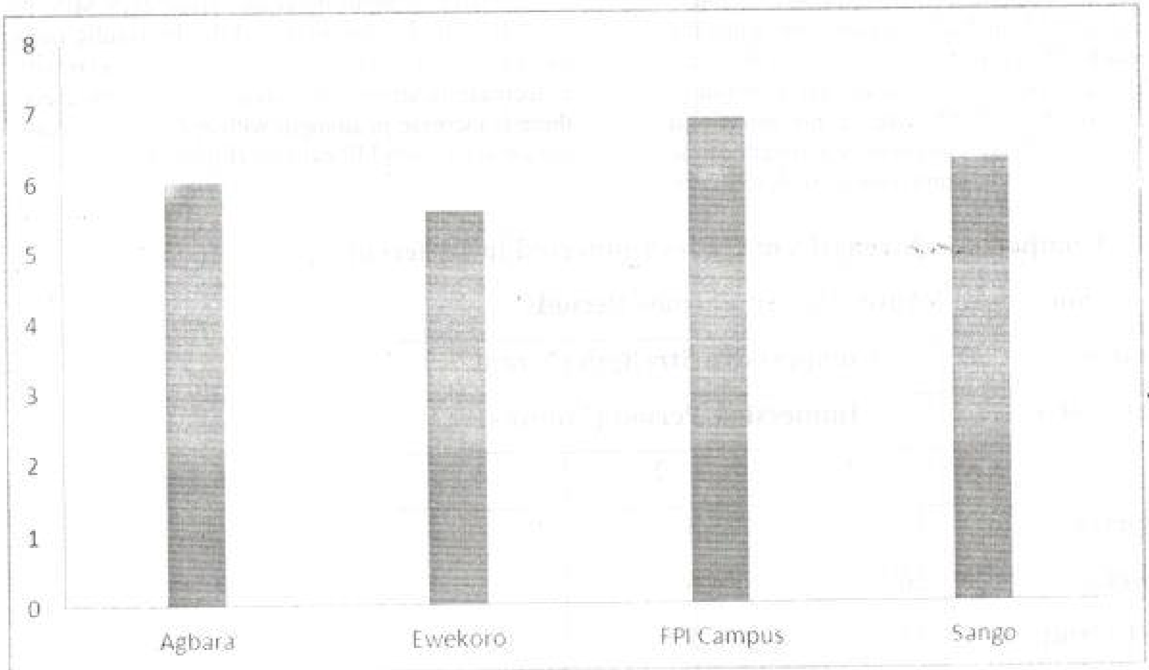

Figure 2: p^H Values of rainwater sample from the study areas.

It is a well-known fact that after vehicle and utility emissions, cement manufacturing is the largest industrial producer of CO_2 accounting for over 50% of all industrial CO_2 emissions; for every tonne of cement produced, 1 to 1.25 tonnes of CO_2 are produced [ICLEI, 2004]. Thus, the acidic nature of rainwater from Ewekoro is a confirmation of the finding.

In addition, a visit to the factory site at Ewekoro reveals heavy emissions released into the atmosphere (Figure 3). Similar reason could be adduced for the slight acid rainwater at Agbara and Sango as the areas are industrial centres for brewery, pharmaceuticals, food, petrochemicals factories. Proximity of these areas to metropolitan city, Lagos State, could also contribute to the low p^H value in these areas.

Figure 3: Release of emissions into the atmosphere during cement production at Lafarge Cement Company in Ewekoro.

Our values are comparable with those got for Ikeja, Oshodi and Odongunyo in Lagos State. Dinrifo et al (2010) show that the p^H values for these industrial areas was 6.2, 6.3, and 6.4. However, none of these sites is cement factory. FPI campus is purely academic environment so, less or no greenhouse gas is released into the atmosphere. Hence, the p^H value is very close to neutral (6.9).

Effect of Acid Rainwater on Strength/Durability

The compressive strength of the cube cured in fresh water is 26.5MPa. However, Table 1 shows the effects on the compressive strength when 28-day cube is immersed in different rainwater from the study areas for the period of 1, 2 and 3 months.

In Table 1, initially (at the end of first 1 month of immersion of the cube) there is no significant variation in the 28-day compressive strength of the cube. However, as the immersion period increases there is a trend of decrease in strength. As for the cube immersed in water from Ewekoro, the compressive strength decreases from 26.5 MPa to 23.7MPa (10.6% decrease), while the results from that of Agbara and Sango are relatively similar with a decrease in strength by about 5.5%. Conversely, there is increase in strength with ages of immersion in rainwater from FPI campus (Figure 4).

Table 1: Compressive Strengths of Cubes Immersed in Different Sources of Rainwater for Various Periods

Source of Rainwater	Compressive Strength (N/mm^2) Immersion Period (Months)		
	1	2	3
Agbara	26	25.3	25
Ewekoro	26	24.5	23.7
FPI Campus	27	28.5	29.8
Sango	26	25.4	24.8

The relative decrease in compressive strength from could be attributed to the acidic environment characterised by the rainwater collected from the industrial areas.

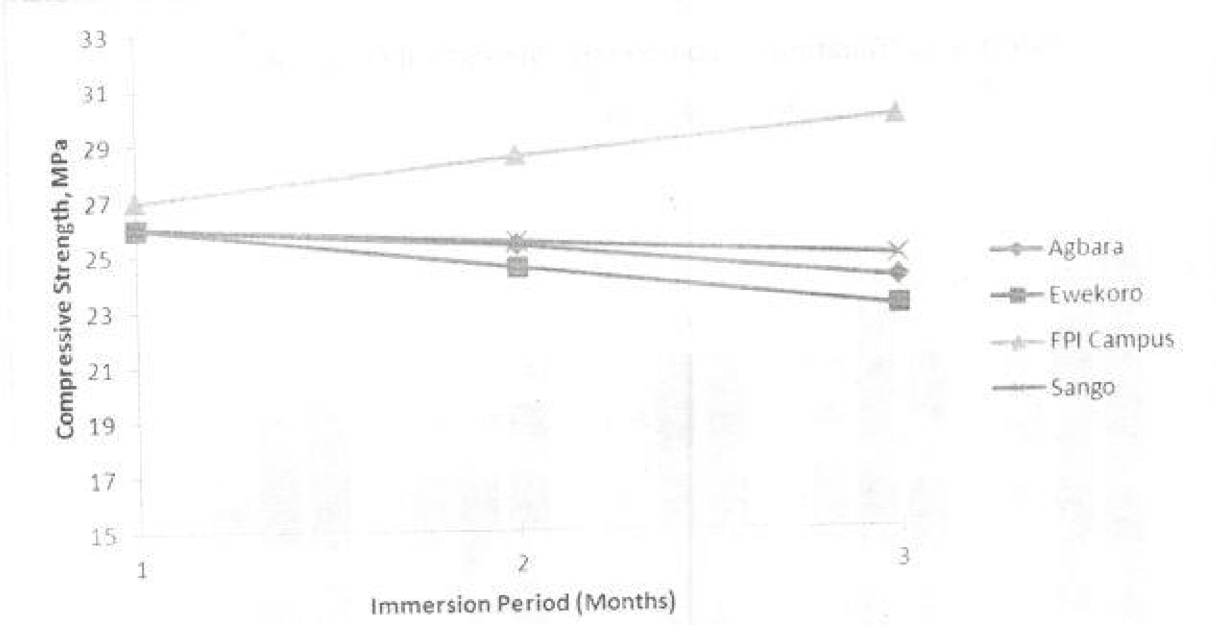

Figure 4: Variation of Compressive Strength with duration of Immersion in rainwater samples

This could be as a result of interference in the p^H value of the concrete. Mehta and Monteiro (2006) opine that Portland cement concrete would be in a state of chemical disequilibrium when it is exposed to acidic environmental conditions. This situation, reduction of the alkalinity of the pore fluid, eventually leads to destabilization of the cementitious products of hydration. Thus, the compressive strength is ultimately reduced.

In addition to decrease in strength, it was also observed that there were spalling at the edges of the cubes immersed in rainwater from the industrial areas but more pronounced in sample from Ewekoro. The concrete spalling is also observed to increase with time. Concrete spalling, increase in the porosity and permeability are indications of chemical (acidic) attack on concrete (Mehta and Monteiro, 2006).

Effect of Temperature Rise on Concrete Properties

The result of the compressive strength of the cubes when temperatures are varied from 35^{0}C to 60^{0}C at an interval of 5^{0}C at different duration is shown in Figure 5. The temperature ranges do not have any significant impact on the compressive strength of the concrete cube. Also, no noticeable shrinkage or crack was detected on all the cubes.

John and Ban Seng (2003) reported that concrete does not start losing its strength nor does it exhibit physical degradation due to increase in temperature until when it rises up to 300^{0}C. Initially at 150^{0}C upwards, some degradation loss of water from silicate hydrates and from Portlandite (calcium hydroxide) can occur but above 300°C the loss of bound water from the hydration products becomes more prominent and further strength loss will occur. Nevertheless, at our present intensity of temperature of about 30^{0}C, concrete deterioration occurs imperceptibly everyday when exposed to heat. But a major effect may not be seen until for a long period say 50 years.

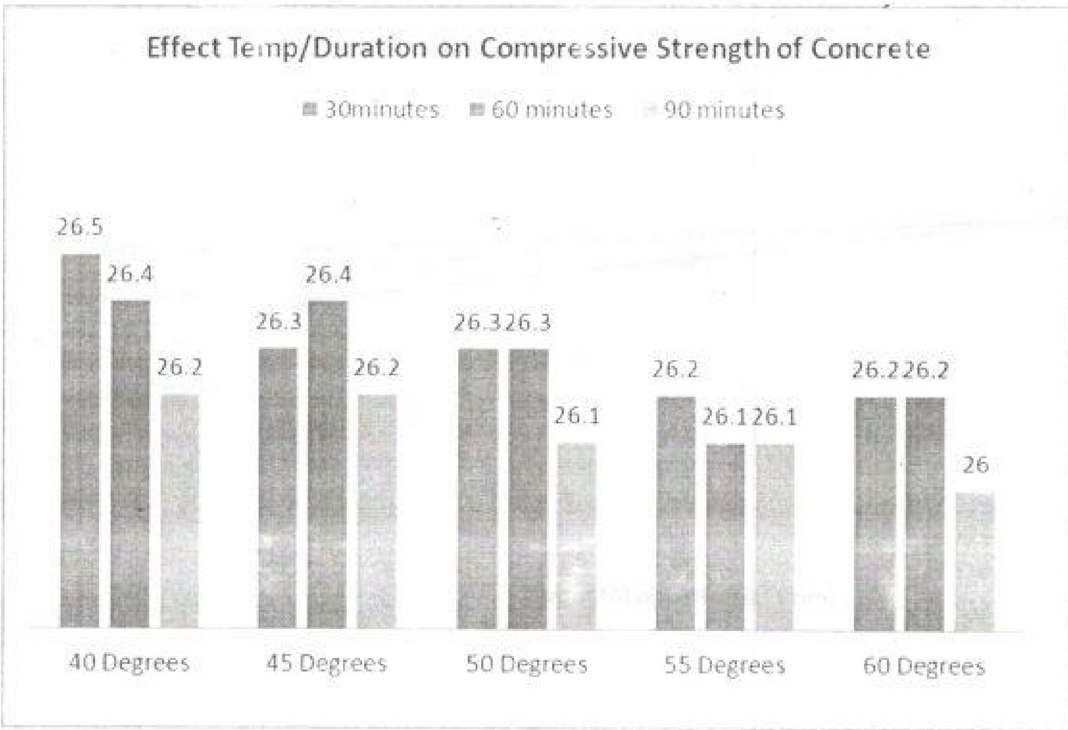

Figure 5: Effect Temp/Duration on Compressive Strength of Concrete

Since it is obvious that the climatic temperature could not reach 300^{0}C, then it could be concluded that global warming because of climate change may not have serious effect on the strength of the concrete. However, caution should be taken to avoid activities that could cause fluctuation in temperature as this could lead to freeze-thawing in concrete.

CONCLUSION

The following conclusion can be drawn from the foregoing findings that:

Though every rain is acidic as long as CO_2 exists in the atmosphere, but its concentration increases due to industrial emission.

Acid rain, due to industrial emission, as an element of climate change could bring about reduction in the compressive strength of concrete by as much as 10 percent depending on the severity of climate change.

Acid rain affects the aesthetics of concrete elements through the spalling of concrete edge and surface cracking.

Temperature as an element of climate does not have immediate effect on the properties of concrete when the prevailing temperature is below 300°C.

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