Adamawa State University Journal of Scientific Research
Volume 7 Number 2, August, 2019; Article no. ADSUJSR 0702025
ISSN:2705-1900(Online); ISSN: 2251-0702 (Print)
http://www.adsujsr.com

Study on Deterioration of Concrete Blend under Elevated Temperature in an Acidic Environment

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Abstract:
This study aimed at investigating the effect of deterioration of concrete produced with cement being partially replaced with silica fume and cow horn ash under elevated temperature in an acidic environment. The performance of the test concrete cubes was done by exposing them to elevated temperatures of 200°C, 400°C, 600°C and 800°C, and allowed to cool down to room temperature, the concrete cubes were cured in an acidic medium before testing for their properties. Both the physical and thermal properties of the concrete cubes were determined. The concrete produced by blending cement with 10% silica fume and cow horn ash with an average percentage loss of 23.04% retained more of its compressive strength when exposed to the different temperatures, than concrete produced using only OPC. The flexural strength of both the control concrete (at 0% OPC replacement) and OPC/ silica fume and cow horn ash blended concrete (at 10% OPC replacement) decreased as the temperature increased. The replacement of OPC by 10% silica fume and cow horn ash increased the Environmental resistance of the concrete by 11 cycles than the 0% OPC concrete at the same temperature and highly resistance to an acidic environment under the same curing condition, the result shows that, blending OPC with silica fume and cow horn ash in concrete performed better at an aggressive environment under elevated temperatures than concrete produced with only OPC. Therefore, the replacement of OPC with 10% silica fume and cow horn ash can be applied as a fire resisting bonding material in concrete.

Keywords: Blended Concrete, Elevated Temperatures, Ordinary Portland cement (OPC), Performance, Silica Fume (sf), Cow Horn Ash (cha)

Introduction

Concrete is durable in most natural environments; however, concrete is sometimes used in areas where it is exposed to substances that can attack and deteriorate it. (Kosmatka,Johani,Wlhi and Bryton, 2002) The first line of defence against chemical attack is to use quality concrete with maximum chemical resistance, this is enhanced by the application of protective treatments in severe environments to keep corrosive substances from contacting the concrete or to improve the chemical resistance of the concrete surface. Protective surface treatments are not infallible, as they can deteriorate or be damaged during or after construction, leaving the durability of the concrete element up to the chemical resistance of the concrete itself. Proper maintenance—including regularly scheduled cleaning or sweeping, and immediate removal of spilled materials—is a simple way to maximize the useful service life of both coated and uncoated concrete surfaces.

Degradation of concretes is attributable to inadequate mix-design; anyway some environments are so aggressive that requiring additional care in order to increase durability (Delagrave,1994). Fundamental principles and special techniques involves in concrete that improve the chemical resistance of concrete refer to Design and Control of Concrete Mixtures (Al-Amoudi, 2002).

Huge amounts of money is spent every year on the restoration of the concrete on structures and manufactured elements deteriorated by different types of degradation. A study conducted by Ccresme (2006) revealed that the prize of the rehabilitation for degraded concrete structures (17.038 billion €) exceeds the prize for new structures (14.525 billion €) in the public administration. Degradation of concretes can be as a result of inadequate mix-design; anyway some environments are so aggressive that requiring additional care in order to increase durability (Delagrave, 1994). One of the most aggressive environments for concrete is the acidic one, such as in the inner Walls of sewer pipes, there are hundred kilometres of problematic sewer pipes; for example, in the Los Angeles County over 320 km of pipes are interested by this problem, and the prize of the rehabilitation will exceed $1 billion (Mehta 2003).

Deterioration of sewer pipes made with concrete, is a great problem when service life is less than 30 ears, and maintenance or even replacement of damaged concrete sewer pipes are required The prescriptions to be adopted are described in the European Standard EN 206-1 ("Concrete part 1: Specification, performance, production and conformity").

Asbestos is a naturally occurring mineral substance that can be pulled into a fluffy consistency (Haynes 2008). Asbestos fibers are soft and flexible yet resistant to heat, electricity and chemical corrosion (Flatt 2002). Pure asbestos is an effective insulator, and it can also be mixed into cloth, paper, cement, plastic and other materials to make them stronger (Haynes 2010). These qualities once made asbestos very profitable for business, but unfortunately, they also make asbestos highly toxic which today it has become a treat to our health, therefore asbestos is no longer an alternative material for sewer pipes.

The main characteristic of this norm consists in the classification of the environments where the concrete construction will be erected, the problem of the degradation interests all the modern society, not only in term of money, but also in term of discomfort and safety. To achieve a 30+ design life, materials exhibiting long-term durability have to be selected. However, an extensive characterization of the most common concrete used for this application lacks due to the complexity of the chemical attack during service life.

The processes leading to corrosion of the concrete are really complex. As previously described by some authors Hill, (2003) Hydrogen sulphide produced by anaerobic is released into the flowing wastewater. Then, it diffuses into the atmosphere and re-dissolves in the condensate on the portion of the pipe above the wastewater, where microorganisms, such as *Thiobacillus thiooxidants,* growing on this surface, convert aerobically hydrogen sulphite to sulphuric acid, which reacts with the concrete (Durning, et, al.1991). In most cases the pH on the surface is very low (in the worst case the pH is 0.5) (Mehta 2000). The scheme of this process is reported in the figure1.

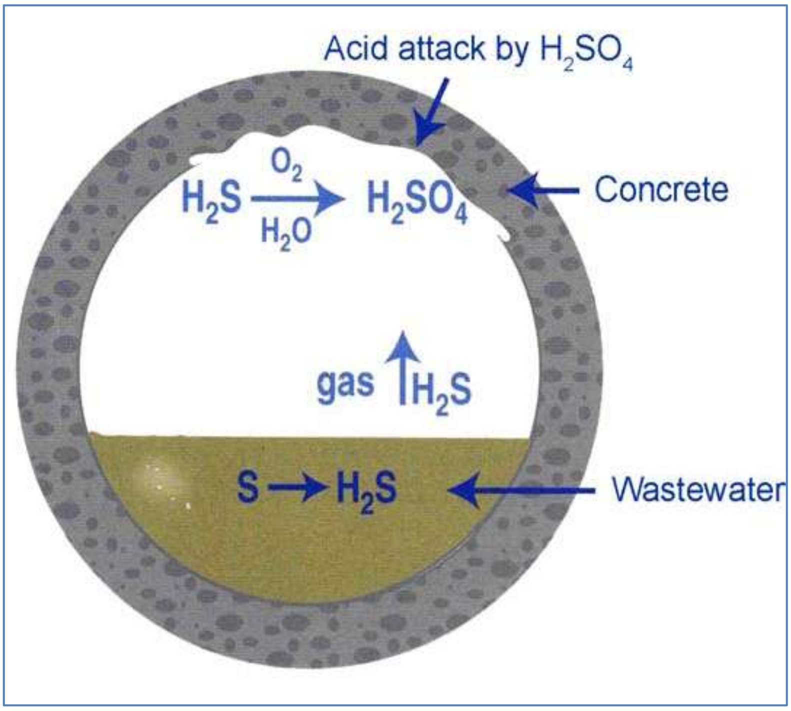

Figure 1: Sewer pipe degradation scheme

The acid attacks first the calcium hydroxide and even tobermorite gel, when portlandite is not more available. Accordingly, under attack, calcium hydroxide forms gypsum and the calcium silicate hydrate (C-S-H) forms both anhydrous gypsum and an incoherent mass hydrated silicate as reported in the following equations:

$$Ca(OH)_{2(s)} + H_2SO_{4(aq)} \rightarrow CaSO_4 \cdot 2H_2O_{(s)} \text{ .... (1)}$$

$$C_3S_2H_{3(s)} + H_2SO_{4(aq)} \rightarrow CaSO_4 \cdot 2H_2O_{(s)} + C_2S_2H_{2(s)} \text{ ....(2)}$$

$$CaO \cdot SiO_2 \cdot 2H_2O + H_2SO_4 \rightarrow CaSO_4 + Si(OH)_4 + H_2O \text{ ....(3)}$$

This corroded layer is highly porous. The growth rate of the corroded layer is determined by the diffusion of the acid through the corroded layer to the reaction front and by the reaction rate of the acid with undamaged concrete. In a previous paper (Delagrave, et, al.1994), it was reported that the rates of degradation of standard mortars are influenced by the presence and the thickness of the layer generated by the degradation products, e.g. calcium sulphate, which slow the diffusion of reactive species. In a second step calcium aluminates hydrate reacts with sodium sulphate ions from sulphuric acid to form ettringite

$$3CaO \cdot Al_2O_3 \cdot 6H_2O + 3(CaSO_4 \cdot 2H_2O) + 14H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O \text{ .... (4)}$$

However, different types of sulphate ions can be found in the wastewater. In the presence of a sodium sulphate source (>8000 ppm of SO_4--) (Santhanam,2002), calcium hydroxide reacts to form secondary gypsum. Consequently, the latter can also participate in secondary ettringite formation. It is important to find out how to control these processes in order to increase the life of the facilities. The reaction equations in the cases of sodium, magnesium or ammonium sulphate are the following:

$$Ca(OH)_2 + Na_2SO_4 \cdot 10H_2O \rightarrow CaSO_4 \cdot 2H_2O + 2NaOH \text{ ....(5)}$$

$$Ca(OH)_2 + MgSO_4 \rightarrow CaSO_4 + Mg(OH)_2 \text{ ....(6)}$$

$$3CaO \cdot Al_2O_3 \cdot 6H_2O + 3MgSO_4 \rightarrow 3CaSO_4 + 2Al(OH)_3 + Mg(OH)_2 \text{ ....(7)}$$

$$Ca(OH)_2 + (NH_4)_2SO_4 \rightarrow CaSO_4 \cdot 2H_2O + 2NH_3 \text{ ....(8)}$$

The literature results lacking in prediction of the concrete resistance, because the experiments neglected both the presence of aggregate and the real conditions in the sewage pipes, Actually, it has been observed that the rate of degradation is higher just above the waterline at the sides of the pipes, where the fluctuating water level continually washes away the sulphate deposits, reducing the degradation resistance.

Therefore, to check leaching of sulphate which affect the surface of the concrete material and have negative influence on the engineering properties of concrete structures requires a systematic use of pozzalanas which tends to improve concrete workability, cohesiveness, finish, ultimate strength and durability as well as solve many problems experienced with concrete all for less cost. Hence, this study will carefully outline ways to produce quality concrete through a synergetic mixture of silica fume (sf) and cow horn ash (cha) which may proffer solutions to the effect of sulphate (so_4) in cement and concrete as a whole in an aggressive environment.

Materials and Methods

To check leaching of sulphate which affects the surface of the concrete material and have negative influence on the engineering properties of concrete structures, systematic use of silica fume and cow horn ash was used which may tend to improve concrete workability, cohesiveness, finish, ultimate strength and durability as well as solve many problems experienced with concrete all for less cost. Hence, this study carefully outline ways to produce quality concrete through a synergetic mixture of silica fume and cow horn ash under elevated temperature which may proffer solutions to the effect of sulphate (so_4) in cement and concrete as a whole. In order to understand the degradation on concrete, different sets of experiments will be performed on concretes prepared with 5%,10%, 15% and 20% of silica fume and cow horn ash as replacement of cements. Twenty Five concrete cubes without silica fume and cow horn ash was prepared at the concrete lab. With The following dimensions: diameter 200mm x200mm x200mm. Two hundred and fifty concrete cubes with silica fume and cow horn ash was prepared at the concrete lab. With The following dimensions: diameter 200mm x200mm x200mm

Materials Used

Cement

Ordinary Portland cement of 53 grades available in local market was used in the investigation. The cement used was tested for various proportions as per IS 4031 – 1988 and found to be confirming to various specifications of IS 12269-1987.

Coarse Aggregate

Basalt originates from "hot spot" volcanoes, massive basalt flows and mid oceanic ridges. Basalt is a dark-colour, fine-grained, igneous rock composed mainly of plagioclase and pyroxene minerals. In present investigation Crushed basalt metal of Size 2 to 5 mm will be used as Coarse Aggregate and Specific gravity will be tested as it will be obtained from local source.

Quartz Sand

Quartz has a hardness of 7 on Mohs scale and a density of 2.65 g/cm³. Quartz is a common constituent of granite, sandstone, limestone, and many other igneous, sedimentary, and metamorphic rocks. It has a hexagonal crystal structure and is made of trigonal crystallized silica. Present investigations of the sand properties will be made.

Cow horn ash

particles were varied in the polyester from 5 to 20 wt%. the thermogravimetric analysis and cone calorimeter test were used to determine the flame reterded of the developed composite. Concrete cylinders 30×200 cm (4×8 in) in size were cast according to ASTM C511 (Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory). Three binder types were used including: ordinary portland cement (OPC), with 5%,10%,15% and 20%silica fume (SF), OPC with 5%,10%,15% and 20% of cow horn ash .

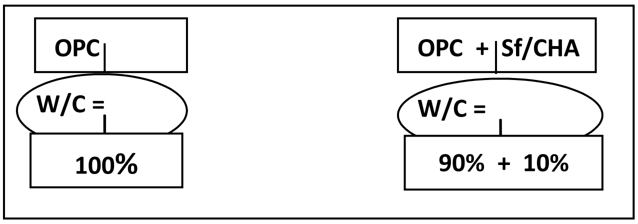

Figure 2: Experimental programme to study the effect of sf/cha pozzolana blended cement concrete at elevated temperature

Curing conditions

All concrete cylinders were cured for 28 days in a moist room with RH ≥ 95% and T = 20°C [68°F] before exposure to the sulphate environment. The curing was carried out according to ASTM C511 (Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes).

Environmental Exposure Conditions

According to Thaulow and Sahu (2004), the most commonly found salt on scaled concrete surfaces exposed to environments conducive to physical sulphate attack is sodium sulphate. Previous studies by Aye and Oguchi (2011), and Haynes et al., (2008 and 2010) found higher surface scaling for concrete partially immersed in 5% sodium sulpahte compared to that exposed to other salts such as magnesium sulphate, sodium carbonate, and sodium chloride under the same exposure conditions (i.e. similar temperature, relative humidity (RH), and sulphate concentration). In addition, Haynes et al., (2008) found that surface scaling escalated drastically when the concrete was exposed to cyclic temperature and RH consisting of two weeks at temperature = 20°C [68°F] and RH = 82% followed by two weeks at temperature = 40°C [104°F] and RH = 31% . Therefore, all concrete cylinders were partially Immersed in a 5% sodium sulphate solution and placed inside a walk-in Environmental chamber with cycling temperature and RH. To accelerate the Experiment, cycles were reduced to one week at temperature = 20°C [68°F] and RH =

82% followed by one week at temperature = 40°C [104°F] and RH = 31%.

In this research, the specimens which were casted cured for 28days subjected to varying temperature of 200^0C, 400^0C, 600^0C, and 800^0C, before submerged in to the sulphuric solution medium for a period 90 days each . The first specimen was maintained at room temperature. Second, third, fourth, fifth and sixth specimen was heated to varying temperature for 3 hours and immersed sulphate solution of P^H=2 for 24 hour, before testing them for water absorption , compressive strength, durability, chemical test, resistance to degradation test, change in volume test.

Results and Discussion

Density of unheated and heated concrete cubes

The density of the test cubes is determined before and after the heating. The values obtained for the unheated and heated concrete cubes are shown in fig 1. The result of the density indicates that, there is a relationship between the density and temperature change. The application of heat to the test cubes reduces its density relatively. Also, increasing the temperature at which the test cube is exposed to, the less the density of the concrete.

Compressive strength

Fig. 2 illustrate the typical development of compressive strength for the 0% and 10% OPC replacement in the control and blended cement concrete subjected to a temperature range of 200^oC to 800^oC for two hours. The compressive strength of concrete cubes made of 0% OPC replacement increased with temperature up to 400oC and then decreased up to 8000C. The result also shows that, the 10% silica fumes and cow horn ash/OPC blended cement concrete increased in compressive strength as the treatment temperature increased up to 600^oC, and decreased at the temperature of 800^oC. For the control concrete at 0% OPC replacement, the increased in strength up to 400^oC may be the result of the hydration of un-hydrated cement constituents due from the heat generated. For the 10% OPC replacement in the blended cement concrete, the increased in compressive strength up to 600^oC may be due to the pozzolanic reaction of the primary chemical constituents of the Silica fume/cow horn ash pozzolana that are deposited within the pores of the concrete. The ability of the blended cement concrete to increase in strength even at 600oC, is as a result of the reduction in Ca(OH)2 content, by the action of SiO2 and Al2O3 which are elements in the cow horn ash. The performance of the concrete specimens exposed to the chloride and sulphate environment was evaluated, measuring the chloride diffusion and reduction in compressive strength due to sulphate attack. The results indicated that concrete blended with silica fume/cow horn ash is more resistance to aggressive environment than the ordinary concrete with zero % replacement as shown in fig 3. The result shows that the presence of silica fume and cow horn ash minimises the effect of sulphate attack on concrete also, the mix design parameters, such as water–cement ratio and cement content, significantly affected both the chloride diffusion and the sulphate resistance of concrete. Similarly, the level of consolidation and the period of curing Impact of Aggressive Environment on Concrete influenced the performance of concrete in the aggressive environment.

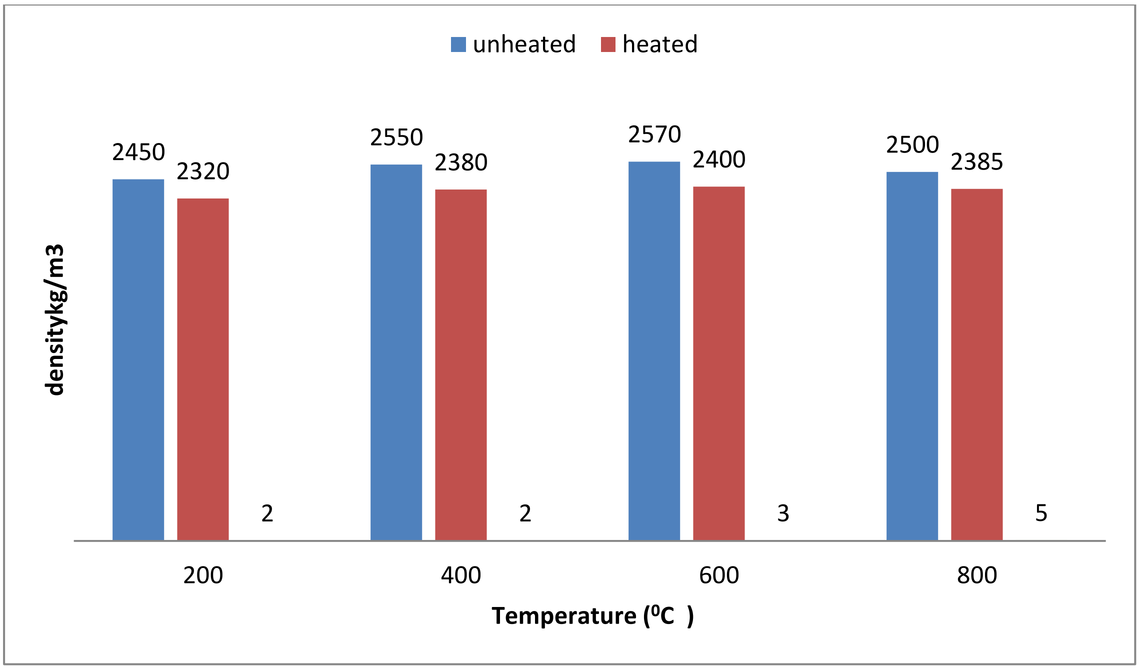

Figure 3: Density of unheated and heated cubes different temperatures for 10% replacement

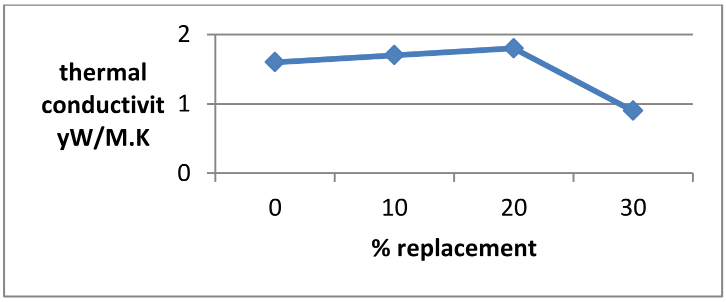

Figure 4: Variation of thermal conductivity with percentage replacement of cement content.

Table1: Variation of Compressive Strength with different Temperature Range

Percentage Replacement (%)	Water/Cement Ratio	Compressive Strength N/mm^2				
		Room Temperature	200^0c	400^0c	600^0c	800^0c
0	0.6	20.15	23.31	24.42	18.44	12.22
10	0.6	15.06	23.73	24.61	18.67	14.20

Table 2: Variation of Flexural Strength with different Temperature Range

Percentage Replacement (%)	Water/Cement Ratio	Flexural Strength (N/mm^2)				
		Room Temperature	200^oC	400^oC	600^oC	800^oC
0	0.6	4.16	2.55	2.1	1.02	Nil
10	0.6	4.71	3.25	2.82	1.84	Nil

Table 3: Aggressive Environment Resistance Test at 400^{O}C

Percentage Replacement (%)	Number of Resistance in Cycles			
	Test 1	Test 2	Test 3	Average Cycle
0	3	5	4	4
10	12	14	12	13

Conclusions

Based on the present study we can conclude that aggressive environment influence the hardened properties of concrete and an essential research has to be done to enable concrete to fill its role. Water cement ratio is one of factor dominating the performance of concrete. Ordinary Portland can be replaced by Portland pozzolana cements but it needs study. Epoxy

Recommendation

It was found that the most influenced item from Cow Horn Ash and silica fume on properties of Concrete is the silicon oxides and their optimum Temperature. Therefore, by using Temperature it has a positive effect on the properties of Concrete. As a future research, it is recommended to develop high quality concrete mix by introducing pozzolanas as a factor as well as water cement ratio and total aggregate to cement ratio taking into consideration the optimum percentage of pozzalana 10%.

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