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Effect of Saw Dust ash (SDA) Pozzolana on the Performance of Blended Cement Paste Concrete at High Temperatures.

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Abstract

This study is aim at investigating the thermal stability of concrete paste blended with ordinary Portland cement and saw dust ash (OPC/SDA). The SDA is thermally activated at 800oC for 2 hours and the concrete pastes prepared with constant consistency. The pastes were kept in moulds at room temperature and 100% relative humidity for 24 hours and then hydrated for 28 days under water. The hydrated concrete pastes were exposed for 2 hours to temperatures of 200, 400, 600, and 800oC. The hydrated concrete specimens were tested for compressive strength and thermal shock stability after heat treatment. It was found that, the compressive strength of the control cement paste concrete increase up to 400oC and suffers a more loss of compressive strength as the treatment temperatures were increased. However, the blended cement paste concrete experience an increase in compressive strength with temperature up to 600oC and then, the strength decrease as the treatment temperature was increased up to 800oC. The replacement of OPC with 10% SDA in the blended cement paste concrete increases the thermal shock resistance by about 4 times that of the control cement paste concrete. Blending of OPC with about 10% of SDA in concrete can improve on its thermal stability and durability.

Keywords: Blended Cement, Cement Paste, Concrete, Performance, Saw Dust Ash (SDA), Temperature.

1. Introduction

The most commonest type of cement used as a basic ingredient of concrete, mortar, and plaster is the Portland cement (Concrete – Wikipedia). According to Neville (1992) In Matawal (2001), Portland cement is made by blending a mixture of calcareous (lime containing) materials and argillaceous (clay) materials. The raw materials are carefully proportioned to provide the desired amount of lime, silica, aluminium oxide and iron oxide. Ordinary Portland cement (OPC) consists of four clinker minerals of which when mixed with water, its phases start to hydrate. The reaction of tri-calcium silicate (Ca3S) and tetra-calcium alumina-ferrite (Ca4AlF) predominates at the early ages of hydration. The reaction of Ca3S and Ca2S predominates from about the time of initial set onward forming calcium silicate hydrates and calcium hydroxides. Neville (1981) explained that when water is added to cement, the basic compounds present are transferred to new compounds by some chemical reactions. The resulting elements of this chemical action contribute to the different properties of cement in concrete such as setting and strength development. Each of the four major compounds in Portland cement contributes to the behaviour of the cement as it proceeds from the plastic to the solid (hardened) state after hydration. Knowledge of the behaviour of each of these major compounds, upon hydration, permits us to understand the action of the pozzolanas (Matawal, 2005).

Concrete when fresh, is a liquid paste that can be moulded into any desired shape and yet develops strength to carry different loadings, when matured. This unique characteristic advantage of concrete made it to be the more preferred choice for application in the construction industry. The cement component as a constituent of concrete is the main binder in translating the liquid paste into a rigid strong concrete. In recent times, researches have shown that pozzolanas can produce concrete that can be relatively compared with normal concrete in its characteristics (Khoury, 1996; Sumaila and Job, 1999; Dashan and Kamang, 1999; Abdulahi, 2006). The replacement of ordinary Portland cement (OPC) by a percentage of pozzolanic material improves the strength and durability of concrete. There are certain materials used as cementitious concrete constituents along side OPC such as, Fly ash, Granulated Blast Furnace Slag (BFS) and silica fume. Other materials with pozzolanic potentials include; Rice husk ash (RHA), saw dust ash (SDA), sugar cane fibre (Bagash) ash, pulverized-fuel ash, groundnut husk ash etc. (Matawal, 2005).

When fine pozzolana particles are dispersed in concrete paste, they enhanced the precipitation of the hydration product. The reaction between the amorphous silica of the pozzolana and the calcium hydroxide ($Ca(OH)_2$) produced by the cement hydration reaction makes the concrete paste to be more homogeneous and dense (Morsy and Shebl, 2007). The physical effect of the fine grains allows denser packing within the cement and reduces the wall effect in the transition zone between the cement paste and aggregates. This weaker zone is strengthened due to the higher bond developed between these two phases, improving the concrete microstructure and properties (Morsy and Shebl, 2007). This effect of the pozzolana depends not only on the pozzolanic reaction, but on the physical or filler effect of the particles in the mixture.

Concrete, under normal atmospheric conditions, is typically exposed to temperatures below 50oC. However, in fire conditions, concrete can be exposed to temperatures of up to 1200oC in less than 2 hours. When heat is conducted in concrete, many changes occur in its physical structure, chemical composition and fluid content. Therefore, the mechanical properties of concrete, in particular strength and stiffness, when exposed to high temperatures are significantly altered. Generally, it can be said that concrete has good properties with respect to fire resistance when exposed to a temperature of up to 1000oC (Naus, 2006). Compressive strength of concrete is generally considered to be its most valuable property. Thermal gradients affect the concrete strength as well as its stiffness. The general trend for a strength loss with increasing temperature reflects the influence of the cement paste and the increasing role of the aggregate materials at higher temperatures. Factors have been identified that may contribute to the general trend for loss of compressive strength with increasing temperature: aggregate damage; weakening of the cement paste-aggregate bond; and weakening of the cement paste due to an increase in porosity on dehydration, partial breakdown of the C-S-H, chemical transformation on hydrothermal reactions, and development of cracking (Khoury, 1996).

A number of material and environmental-related factors affect the response of concrete materials to elevated-temperature conditions. As many of the aggregate materials are thermally stable up to temperatures of 300°C to 350°C, which includes the temperature range considered for most applications, the compressive strength of concrete at elevated temperature is dependent in large measure on the interaction between the cement pastes and aggregate. Concrete offers great fire resistance to structures. It is reasonably physically stable to about 550oC, and even above that temperature it usually does not fail dramatically (Erlin and Hime, 2004). Concrete's thermal properties protect reinforcing steel and pre-stressing steel, and it does not fall off structural steel members like some fireproofing coatings do. All of this does not mean that concrete is not adversely affected by fire or heat. In the event of fire, concrete structures are affected by various processes. This leads to degradation of the material and potentially spalling of the near-surface concrete layers (Zeiml and Lackner, 2007). When concrete is exposed to temperatures above 100oC, the moisture in the concrete turns to steam. If the temperature rises rapidly than the steam can escape through the concrete matrix, the rising pressures exceed the strength of the concrete and it begins to spall.

The compatibility between the cement paste and the different types of aggregates at ambient temperatures is distorted when exposed to high temperatures. The first process is water evaporation at about 100OC, which is followed by the dehydration of cement gel at about 180OC that weakens the bond within the solid skeleton. The decomposition of concrete binding product, calcium hydroxide, into calcium oxide and water, which starts at around 400oC, is a reversible process that is most rapid at 500oC (Bazant and Kaplan, 1996). This is followed by expansion due to thermal incompatibility of the limestone constituents, which occur between 450oC and 750oC. These transformations cause a volume increase through thermal expansion of aggregates. After these processes, calcium silicate hydrates in cement paste start decomposing at 700oC. Finally, the decarbonation of concrete and melting of the aggregates is the last stage at the level of 800oC (Bazant and Kaplan, 1996).

The performance of concrete can be measured by the change of its stiffness, strength, or some other property that would affect its main function in service. Because concrete has a relatively low tensile strength, it is normally relied upon to take compressive forces, with tensile forces taken by steel reinforcement. As a consequence, much of the research conducted on concrete at elevated temperature has concentrated on compressive strength as the fundamental property in examining its deterioration. However, it has been noted that the compressive strength may not be as good an indicator of deterioration at elevated temperature as tensile or flexural strength under short-term loading (Sullivan 1979; In Naus, 2006).

Pozzolanic high strength concretes (HSC) are used extensively throughout the world. The application of such concretes is increasing day by day due to their superior structural performance, environmental friendliness, and energy conserving implication (Mehta, 1999). When fine pozzolana particles are dispersed in concrete paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore, this mechanism makes the paste more homogenous and dense as for the distribution of the fine pores. This reaction has a way of improving the resistance of the concrete formed to increase in temperatures.

In this study, the utilization of saw dust ash (SDA) as a pozzolanic addition for cement paste is of considerable importance. The hydration of cement results into the production of calcium hydroxide , which is associated with poor durability especially in high temperatures. The introduction of the chemical components of SDA as a blend to the cement paste will react with the calcium hydroxide thereby generating an additional cementitious phases. This has a major influence on the cement paste resistance to fire. This study therefore aim at investigating the effect of high temperature treatment on the strength property and as well as thermal shock resistance of Ordinary Portland Cement (OPC)/SDA blended concrete.

2. Materials and Methods

The materials used for this investigation were ordinary Portland cement and aggregates. The chemical composition of the starting materials is shown in Table 1. The saw dust ash (SDA) used for this research resulted from waste products of Timber sawn in Timber sheds in Jos. The saw dust came mainly from species of timber such as Mansonia, Mahogany, Obeche and black Afara, which are common in the Nigerian market. The SDA was produced by burning saw dust to a temperature range of 500oC – 600oC using a furnace at the National Metallurgical Development Centre (NMDC). The cooled ash was then grounded to very fine texture and sieved to size less than 212µm. This study is limited to 10% replacement of cement with SDA pozzolana in concrete and its performance when subjected to high temperature. This proportion is based on a study carried out by Sumaila and Job (1999); and also Elinwa and Mahmood (2002); and Matawal (2005) where they suggested an optimum replacement of cement with 10% SDA pozzolana in concrete for workability and strength.

In this study, two concrete mixes of both blends were cast each with 0.60 water/cement ratio. Concrete cubes of sizes 150mm x 150mm x 150mm were cast for each mix. The detail of mix design per cubic meter of concrete is shown in Table 3. In placing the mixed concrete in the moulds, a scoop is moved around the edge of the mould to insure symmetrical distribution of concrete. Each layer is tampered with 25 strokes using a tamping rod. The side of the mould is tap to remove voids that are left by tamping rod. After the top layer had been rodded, the surface is strike-off with a trowel. The specimen is left in the mould for 24 hours, after which the mould is removed and the concrete cubes are in cure in water for proper hydration.

Nominal mix proportion of 1:2:4 ratio was used for the concrete cubes. The material batching was computed by the method of absolute volume because of the difference in specific gravities and bulk densities of the different materials components in the concrete. For the purpose of this study, the tests conducted in this study are only on the hardened concrete cubes where they were subjected to temperature range of 200oC to 800oC. The test carried out on the concrete at elevated temperatures is the cold testing. This was done by heating the test cubes to a specified temperature, which are permitted to stabilize at that temperature for a prescribed period of 2 hours. This is then permitted to slowly cool down to room temperature and the residual properties of the concrete determined. The concrete cubes are cured in water for 28 days. The hardened cement pastes were then dried at room temperature for 48 hours after which, they were kept for 2 hours in an oven at temperature of 200, 400, 600 and 800oC. Each tested temperature was maintained for 2 hours to achieve the thermal steady state. The tested cubes were allowed after heating to cool to room temperature. The compressive strength test was performed on the dried and fired specimens. The average of the results of the three (3) different concrete cubes gives the compressive strength at a particular temperature range. The thermal shock resistance was determined by heating the moulded concrete after 28 days of curing under water for 45 minutes at a temperature of 800oC. This is then followed by immersing the heated cube in water and the cycles are repeated until the samples are broken, damaged or deteriorated.

Table 1 Physical and chemical properties of ordinary Portland cement and saw dust ash

ELEMENTS	ORDINARY PORTLAND CEMENT (OPC)	SAW DUST ASH [SDA]
Insoluble Residue	4.70%	
Specific Surface Area	$358m^2$/Kg	
Specific Gravity		2.03
Moisture Content (MC)		2.06%
Loss on Ignition	8.50%	4.97%
PH Value		10.05
Al_2O_3	6.01%	13.65%
Fe_2O_3	3.22%	13.34%
SiO_2	20.62%	48.95%
CaO	59.60%	5.40%
MgO	3.65%	4.60%
K_2O	0.71%	9.01%
SO_3	2.46%	1.00%
MnO		0.95%
P_2O_5		3.10%
Free Lime	1.38%	
Others	2.35%	

3. Results and Discussion

Table 2 and Figure 1 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 200oC to 800oC 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% SDA/OPC blended cement concrete increased in compressive strength as the treatment temperature increased up to 600oC and decreased at the temperature of 800oC.

For the control concrete at 0% OPC replacement, the increased in strength up to 400oC may be the result of the hydration of un-hydrated cement constituents due from the heat generated. But for the 10% OPC replacement in the blended cement concrete, the increased in compressive strength up to 600oC may be due to the pozzolanic reaction of the major chemical constituents of the SDA 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 SDA. According to Morsy et al (2008), cement matrix with higher volumes of gel-like hydration products and lower crystalline Ca(OH)2 contents has improved fire resistance. The decline in compressive strength of the 0% OPC replacement concrete is noticeable when the temperature is above 400oC while that of the 10% replacement in the blended cement concrete is noticeable at a temperature of above 600oC.

Table 3 shows the result of the rate at which compressive strength is gain or loss with increase in temperature. From the result, the average strength percentage strength gained of the control concrete (at 0% OPC replacement) is 10.22% which is higher than the strength gain in the blended cement concrete (10% OPC replacement) which is 7.59%. Strength gain in the 10% OPC replacement in the blended cement concrete is slower but increased up to a temperature of 600oC due to the pozzolanic activity of the SDA. The hydration of cement consequently results into the liberation of lime. The liberated lime reacts with the pozzolana to increase the strength development of the SDA/OPC blended cement concrete.

The average percentage loss in compressive strength of the 0% OPC replacement concrete at temperature of over 400oC is 29.11%. This is more than the average percentage loss in compressive strength of the SDA/OPC blended cement concrete at a temperature of over 600oC. Since increase in temperature resulted into decreased in densities, it is expected that compressive strength should decrease with increase in temperature.

The thermal shock resistance performance of the concrete cubes is shown in Table 4 and Figure 2 as a result of exposing the tests cubes to an elevated temperature of 800o , the outer surface of the concrete which is in direct contact with the heat tends to expand more than the inner layers. When the heated concrete cube is cool by immersion in water, there is a differential deformation between the outer surface and the inner layers thereby resulting into cracks and deterioration of the concrete. Due to the presence of the constituents of the pozzolanic SDA, the thermal shock resistance of the 10% OPC replacement in the blended cement concrete is considerably higher than that of the control (0% OPC replacement).

Table 2 Variation of compressive strength with different temperature range

Percentage Replacement (%)	**Water/Cement Ratio**	Compressive Strength N/mm^2				
		Room Temperature	**200°C**	**400°C**	**600°C**	**800°C**
0	0.6	20.15	23.31	24.42	18.44	12.22
10	0.6	15.06	15.73	16.09	18.67	14.20

Table 3 Rate of compressive strength gain and loss

Percentage Replacement (%)	**Strength Gain/Loss**				**Average Percentage Gain (%)**	**Average Percentage Loss (%)**
	200°C : Room temperature	**400°C : 200°C**	**600°C : 400°C**	**800°C : 600°C**		
0	1.16	1.05	1.32	1.51	10.22	29.11
10	1.04	1.02	1.16	1.31	7.59	23.94

Table 4 Result of thermal shock resistance test at 800°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

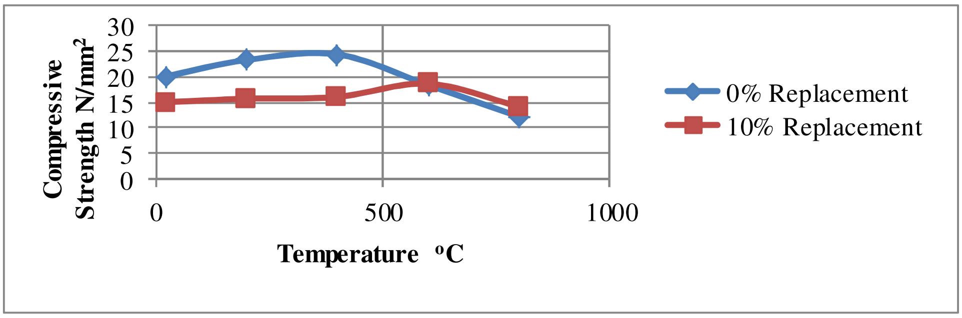

Figure 1 Compressive Strength Development at different Temperatures

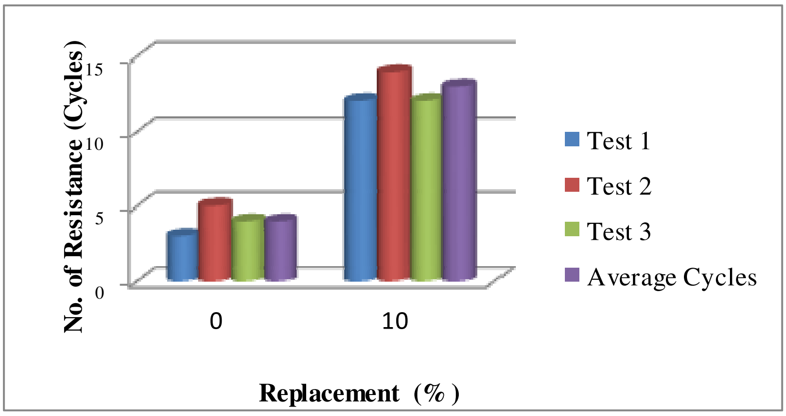

Figure 2 Thermal Shock Resistance

4. **Conclusion**

Based on the investigation carried out, the main conclusion derived from this study may be summarized as follows:

1. Concrete produced by blending cement with 10% SDA increased in compressive strength when heated to 600oC while the compressive strength of concrete produced with OPC reduces at the same temperature.

2. Concrete produced by blending OPC with 10% SDA retained more of its compressive strength at the different temperatures exposed to than the concrete produced using only.

3. Replacement of OPC by 10% SDA increased the thermal shock resistance of the concrete by 11 cycles more than the concrete produced with 100%.

From the tests results, it can be deduced that the replacement of OPC with about 10% SDA in concrete relatively improved performance of concrete at elevated temperature. Blending of OPC with 10% SDA can therefore be applied as a fire resisting bonding material in concrete.

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