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EFFECT OF ELEVATED TEMPERATURE ON THE COMPRESSIVE STRENGTH OF CONCRETE PRODUCED WITH PULVERIZED STEEL MILL SCALE

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ABSTRACT
Concrete materials in structures are usually exposed to high temperatures during fire. The relative properties of concrete after such an exposure are of great importance in terms of the serviceability of buildings. The effect of partial replacement of cement with pulverized steel mill scale (PSMS) on the compressive strength of concrete cubes was investigated in the first test. Furthermore, the influence of elevated temperatures on the compressive strength of the concrete cubes with cement partially replaced with PSMS was examined. For the second test the cubes were exposed to elevated temperatures ranging from the ambient temperature to 750°C in steps of 250°C for 2 hours and allowed to cool for 24 hours. Based on results of tests, partial replacement of cement with 10 % PSMS is recommended for use in concrete production and resistance to elevated temperature. The studies show that at this replacement, the concrete compressive strength is not adversely affected when the elevated temperature reaches 500°C.

Keywords: *pulverized steel mill scales, cement, compressive strength, elevated temperatures*

1. INTRODUCTION

Concrete is the most widely used material for the construction of infrastructural facilities, large and small scale residential facilities and other specialized uses. Cement, fine and coarse aggregates though naturally occurring, still require some industrial processes to meet up with prescribed standards. These require capital. Recent research efforts have now begun to look into the partial or full replacement of some of the constituents of concrete with environmentally friendly and sustainable materials such as industrial and agricultural waste products with the main aim of reducing cost whilst maintaining structural integrity [1–4].The solid waste products generated includes slags, sludge, dusts, rice husk ash, mill scale, etc.

Mill scale is generated during the production of rolling red or hot iron steel billets in rolling mills. The specific production of mill scale is approximately 35–40 kg per ton of produced steel[5]. About 90 % of this mill scale is recycled within the steel manufacturing industries through the sintering plant [6]. The non-recycled portion of mill scale is used in cement manufacturing or in petro-chemical industries [7].

Although there are several studies on the use of mill scale in cement manufacturing and soil stabilization [8, 9], the option of mill scale in concrete as partial replacement of cement under the effect of temperature is seldom explored. The physical changes and chemical decomposition of concrete constituents at elevated temperatures is demonstrated in widely spread cracks, explosive spalling or both. In reinforced concrete members, such changes are reflected by a reduction in the mechanical properties, increase in the permeability of concrete, and weakening of the bond strength between embedded steel and concrete [10-12]. Many studies have been carried out to investigate the effect of the elevated temperature on different concrete specimens [13–15]. It is noted that characteristics such as colour, compressive strength, elasticity, concrete density and surface appearance are affected by temperature [16, 17]. The effect of high temperature on concrete containing pulverized steel mill scale has not been investigated in detail. Therefore, the aim of this study is to investigate the effect of adding pulverized steel mill scales (PSMS), in varying percentages, on the mechanical properties of the concrete under room temperature and after exposure to elevated temperatures

2. MATERIALS AND METHODS

2.1 Materials

The fine aggregate used in this research study was River Sand obtained from Ogun River in Ogun State. It

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was confirmed to be salt free and free from deleterious substances. The coarse aggregate used in this research was granite chippings of 2.36mm to 20mm. Commercial Portland cement, which is produced at Ewekoro in Ogun State, was used in the preparation of all concrete specimens used in this study. The steel mill scales used were obtained from a Steel Milling Company located at an industrial estate of the Lagos Metropolis. They were milled to meet grain size classification of Ordinary Portland cement and sieved. Portable water which was fresh, colourless and odourless and free of organic matter was used in these experiments.

2.2 Methods

2.2.1 Concreting and Specimen Preparations

Mixing of the concrete was done mechanically with the use of a tilting drum mixer, a mix ratio of 1:2:4 was adopted with the percentage of mill scales varying for each mix. The percentage replacement of PSMS values ranged from the control mix of 0% to 40% in steps of 5% till 20% and afterwards 10%. The batching was by weight. After thorough mixing, the concrete was cast into 150mmx150mmx150mm moulds; the fresh concrete was placed in three layers with each layer compacted manually by a tamping rod 25 times. For the first experiment, eighty four (84) standard cubes size of 150mm x 150mm x 150mm were cast. All freshly cast specimens were left in the moulds for 24 hours before de moulded and curing in water until the time of testing. Density and compressive strength tests were conducted on the cube specimens, at 7, 14, 28, and 60day curing ages respectively, in accordance with [18]. . For the second test, seventy-two (72) cubes were cast as the first test but cured only for 28 days. Specimens were heated in a furnace at 250^0C, 500 ^{0}C, and 750^0Ctemperature for 2 hours. The specimens were allowed to cool down for 24 hours till they regained room temperature after which they were weighed and tested for compressive strengths.

2.2.2 Chemical Analyses

The chemical test of Portland cement (Dangote) and the steel mill scale were done in Department of Chemistry, University of Lagos

2.2.3 Setting Times

The initial and final setting times were determined by the use of the Vicats apparatus. The initial setting time was the time taken for the Vicats needle to penetrate to depths less than 25mm while the final setting time according to the British Standard when the penetration of the plunger is 5 $\pm$ 1 mm from the bottom.

2.2.4. Workability

The workability of the fresh concrete mix was determined by the slump test. Fresh concrete was placed into a slump cone in three layers and compacted with a tamping rod to ensure all air pockets were removed. The slump cone was removed and the slump height was determined by measuring the difference between the cone height and the fresh mix. This test was performed for each mix percentage variation of PSMS. The slump test was carried out in accordance with the provisions of[19]. The replacement was done for range of0% to 40% cement replacement with PSMS.

2.2.5 Compressive Strength

Avery Denison Universal Testing machine was used to load the cubes to failure. The loading rate on the cubes was 0. 35 mm/min. The average value of three cubes was recorded as compressive strength value for each percentage replacement in first and second test.

3. RESULTS AND DISCUSSION

3.1 Some Physical Properties of the Materials Used

Table 1 shows the physical properties of the materials used in the experiments. The particle size distribution curves of fine and coarse aggregate is illustrated in Fig. 1 and Fig. 2 respectively.

Table 1: Physical properties of Sand, Granite, cement and PSMS

Physical Property	Sand	Granite	Cement	PSMS
Fines Content (% passing through 0.0063μm sieve)	-	-	99.3	99.73
Dry Density (Kg/m^3)	1410	-	-	-
Bulk Density (Kg/m^3)	1439	1592	1297	2902
Moisture Content (%)	.092	-	-	-
Water Absorption Capacity (%)	0.022	-	-	-
Uniformity Coefficient (Cu)	2.0	1.27		
Coefficient of Uniformity (Cu)	2.39	0.981	-	-

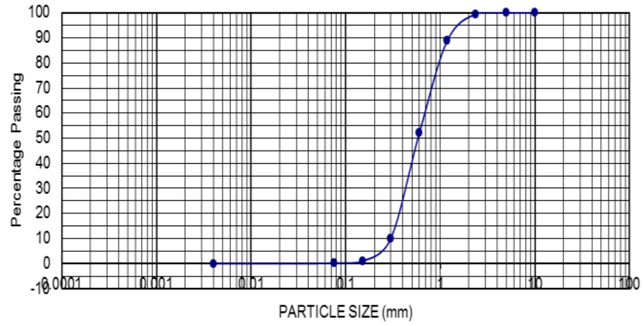

Figure 1: Particle Size Distribution Curve for Sand

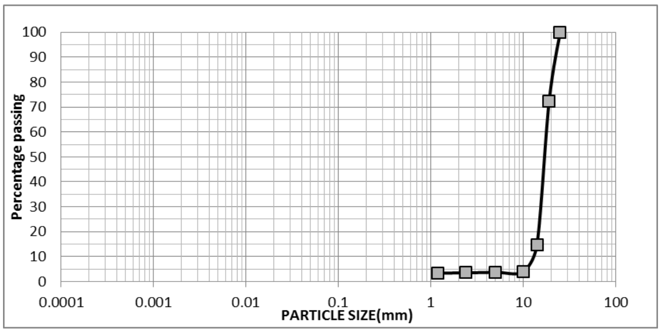

Figure 2: Particle Size Distribution Curve for Coarse Aggregate

Table 2: Physical properties of Sand, Granite, cement and PSMS

Name of Compounds	Ordinary Portland Cement (%)	PSMS (%)
CaO	63.45	30.11
SiO_2	20.34	21.64
MgO	6.10	29.86
Fe_2O_3	2.13	2.41
Al_2O_3	6.10	29.86
SO_3	1.21	-
Na_2O_3	0.27	0.13
K_2O	0.38	0.28
Loss of Ignition	-	12.19
Organic Content	-	0.08

Table 3: Setting Time Values with percentage replacement of PSMS

% Replacement	Initial Setting Time (Mins)	Final Setting Time (Mins)
Control	146	211
5	160	252
10	162	255
15	165	255
20	178	301
30	195	315
40	218	350

Table 4: Slump Test

Cement replacement with PSMS (%)	Slump (mm)	Type of slump	Degree of Workability
0	73.5	True	Medium
5	61.0	True	Medium
10	52.0	True	Medium
15	35.5	Shear	Medium
20	20.5	Collapse	Low
30	17.6	Collapse	Low
40	15.8	Collapse	Low

3.2 Chemical Composition of PSMS

The oxide composition of PSMS is shown in Table 2. Result of the test indicate that PSMS is low in CaO composition than the ordinary Portland cement, it is however slightly higher in silicates. Further, it was observed that the sum of $SiO2 + Al2O3 + Fe2O3$ for PSMS is 53.91%. This value suggested that PSMS is in the same category with class C fly ash characterized by low pozzolanicity [20].

It was also observed that the Loss of Ignition (LOI) of the PSMS is far greater than the LOI of cement. The loss on ignition is a measure of the extent of carbonation and hydration of free lime and free magnesia due to atmospheric exposure. PSMS LOI value of 12.19% is far greater than the limits of 3.0% set by[18].The alkalis (K_2O and Na_2O), with a combined percentage of 0.41% is low, and within the 3% limits of the provisions of[18]. Thus the possibility of the destructive alkali-aggregate reaction is eliminated in concrete containing PSMS [21].

3.3 Setting Time

Table 3 presents the results of investigations of the inclusion of PSMS into the cement matrix on the setting time of cement. The results show that the inclusion of PSMS in the mix increased the setting time of cement paste. The deceleration of the setting times (both initial and final) of cement pastes may have been the result of decreasing volume of hydration compounds as well as the increase in distance between the individual particles as a result of the PSMS particles in the matrix. It was observed that with 5% inclusion of PSMS in the cement based paste, there was an increase of 8.75 and 19.43% in the initial and final setting times respectively. With subsequent increase in percentage substitution of cement with PSMS, the initial and final setting times increased with a maximum increase of 49.3 and 65.87% (initial and final respectively) at 40% replacement value. With these results, it can be inferred that PSMS is a setting time decelerator.

3.4 Workability

The workability of fresh concrete, as determined by the slump test, for all the mix proportions with different percentages of cement replaced with PSMS is presented in Table 4. The results show that slump reduces with increase in PSMS content, in concrete.

3.5 Compressive Strength

Figure 3 presents the value of compressive strength with variation of PSMS content in cement and curing age. At 28-day curing age, the compressive strength varied between 27.10N/mm^2 and 9.93N/mm^2. There is a reduction in compressive strength at 5% replacement with PSMS and the strength of the sample with 10% replacement was more than 4.5% of the control specimen. Reduction in compressive strength was recorded for all 5 replacement in the mix. A gradual increase of compressive strength at 10% was observed with a further decrease for the rest of the replacement.

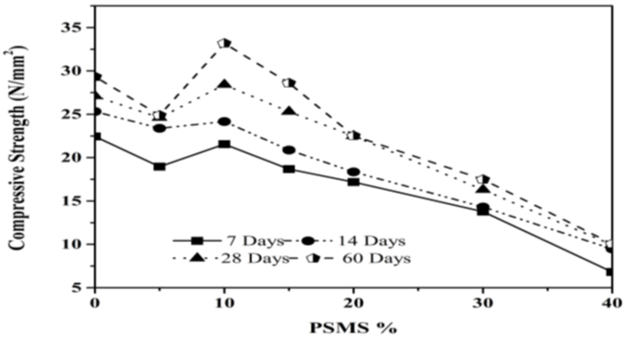

Figure 3: Variation of Compressive Strength with Percentage PSMS and Age

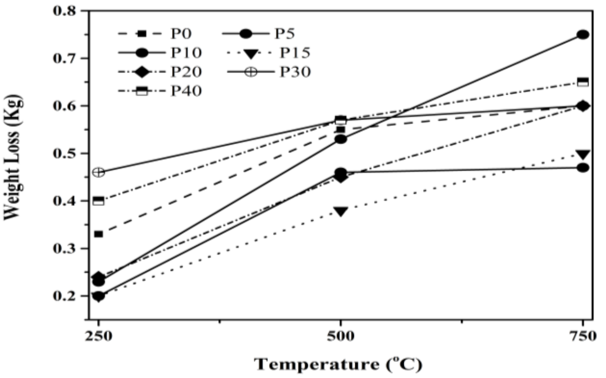

Figure 4: Relationships between Weight Loss (kg) and Temperature Exposure (° C) PSMS

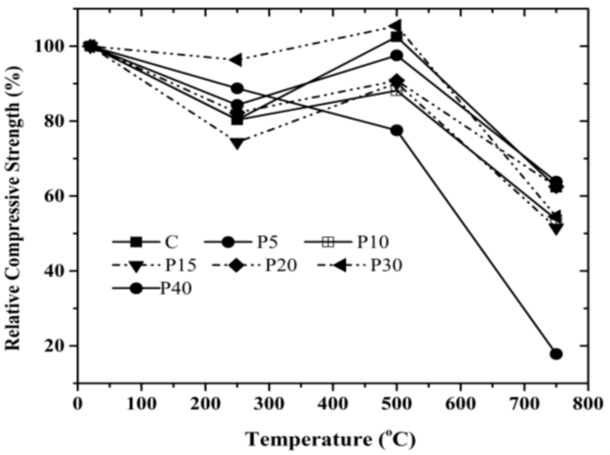

Figure 5: Relative strength of the concrete specimens subjected to elevated temperatures.

This result may have two underlying reasons, the first being that the small amount of silicate in PSMS make it behave like a pozzolanic material. The amount of free silica in PSMS is low; hence a little strength is gained at 10% replacement. The other reason is that there is reduction in the quantity of cement available for the hydration process, this makes the compressive strength to decline afterwards. Figure 3 revealed that at 60 days, the addition of PSMS to concrete specimens does not act as deleterious substances in the mix. The highest 28 day compressive strength of 28.40N/mm^2 was achieved at 10% replacement.

3.6 Effect of Elevated Temperature on Concrete Specimens

3.6.1. Weight loss

The relationship between weight loss and elevated temperatures is presented in Figure 4. It was observed that the weight loss increased with temperature while densities decreased for all replacement values of PSMS in the mix. The unit weights decrease with increasing temperature. The reduction in weight was due to the decrease in moisture content of the cubes and possible changes in the internal structure of the components (coarse aggregates, PSMS, OPC and Fine aggregates) due to the elevated temperatures. The structural integrity of the specimens deteriorates as confirmed by the reduction in weight with increase temperature. The reduction in weight confirms the loss of mass by the concrete material and the increase in the proportion of air voids [22].The compressive strength of thermally treated concrete specimens after cooling was determined. The result shown in Table 6 indicate the relative strength of each specimen at different elevated temperatures. Figure 5 presents the relative compressive strength values of the concrete mixtures after exposure to high temperature. The relative strength was calculated as the percentage of strength retained by concrete with respect to the strength of the unheated specimen.

The perspective of relative compressive strength of concrete, the heating conditions can be divided into three regions of 0^0C - 250^0C, 250^0C - 500^0C and 500^0C - 750^0C. Distinct patterns of strength loss followed by a gain were observed in first two regions and then subsequent sharp loss in the third region. The reduction in relative compressive strength at 250^0C can be attributed to the driving out of free water. There was an increase in relative compressive strength between 250^0C - 500^0C for PSMS concrete and control (with the exception of the 40% replacement specimen). This increase may be due to the hydrothermal interaction of the PSMS particles as a result of temperature rise with the liberated free lime during hydration reaction. Finally, a sharp reduction in relative strength occurred beyond 500^0C due to the loss of crystal water. This is consistent with data by Gupta et al [23].

4. CONCLUSIONS

The following conclusions can be drawn based on the experimental studies presented in this paper:

1. The unit weight of the concrete increased with the partial replacement of cement with PSMS.

2. Maximum compressive strength value for unheated concrete was obtained when cement was replaced with 10 % PSMS.
3. The unit weight of the concrete decreased when it was exposed to elevated temperature.
4. At elevated temperature of 250 degree Celsius compressive strength value of cement replaced with 10 % with PSMS compared favourably with the control.
5. The reduction in the compressive strength of concrete was significantly larger for samples exposed to temperatures higher than 500 degree celsius.

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