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THE EFFECT OF AMORPHOUS SILICA RESIDUE IN THE PRODUCTION OF CONCRETE

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Abstract

In this research work, the effect of amorphous silica residue (ASR) in the production of concrete was investigated. A mix proportion of 1:1.9:3.9 with water/cement ratio of 0.48 was used. The percentage replacement of Ordinary Portland Cement (OPC) with amorphous silica residue was 0%, 5%, 10%, 20% and 30%. Concrete cubes of 150mm x 150mm x 150mm and concrete beams of 150mm x 150mm x 600mm of OPC/ASR were cast and cured at 3, 7, 28, 60 and 90 days. At the end of each hydration period, the three concrete cube and beams for each hydration period were crushed and their average compressive and flexural strength recorded. A total of seventy five (75) concrete cubes and seventy five (75) concrete beams were cast. The result of the compressive strength test for 5-30% replacement of cement with amorphous silica residue ranges from 12.78-38.16N/mm^2 while the control test (0% replacement) ranges from 10.86-26.04N/mm^2. The result of the flexural strength test for the same replacement level of cement with amorphous silica residue ranges from 2.29-11.69N/mm^2 while the control test ranges from 2.14 – 7.80N/mm^2. The initial setting time of OPC/ASR for 5-30% replacement level of cement with amorphous silica residue ranges from 37-53mins while the final setting time ranges from 408-573mins. The initial and final setting time of the control test is 58mins and 580mins respectively. Relevant literature has been cited to justify this research work. The main objective of this work is to determine the effect of amorphous silica residue on the setting time, compressive strength and flexural strength of concrete produced with it.

Keywords: *Compressive strength, flexural strength, amorphous silica residue, setting time*

1.0 Introduction

In the last few decades, many researches have been directed towards the utilization of waste materials in cement and concrete [1]. Not surprisingly, there has been increasing interest in the use of amorphous silica residues as supplementary cementing materials, even though little literature is available on this topic [2].

The amorphous silica residue is a waste material from the technological process used in the manufacture of amorphous silica product. The chemical reactions occurring in the process are complex, but one of the reactions includes the formation of amorphous silica slurry, some of which passes through a filler press in the form of very tiny particles. This amorphous silica residue which is thus a waste material of the process, is then sent to a setting tank to flocculate and finally to landfill disposal.

Initial work conducted by the civil and environmental department of the Louisiana State University, USA was primarily concerned with the characteristics of amorphous silica residue in comparison with a typical silica fume [3]. It is envisaged that the pozzolanic activity of amorphous silica residue would be much higher due to its higher specific surface areas and amorphous characteristics.

This study contributes to the development of a methodology for assessing concrete manufactured from waste. The methodology is based on the study of concrete containing experimental waste (Amorphous Silica Residue) [4].

The durability and the environmental impact of concrete are closely connected to its transport properties which control the kinetics of the penetration of water and aggressive agents into concrete [5]. The movement of chemical species within the material and the leaching of certain chemicals are also closely linked to concrete diffusivity [6]. Finally, the strength characteristics of concrete containing increasing levels of amorphous silica residue were studied to identify the effect of amorphous silica residue on concrete produced with it.

2.0 Literature Review

The chemical composition is an important factor that affects the activity of pozzolanic material. Potential pozzolanic materials contain substantial amount of SIO_2, AL_2O_3 and Fe_2O_3. [7] reported that the total SIO_2, AL_2O_3 and Fe_2O_3 were found to be a good indication of the pozzolanic activity. [8] has set a minimum value of 70% for the sum of SIO_2 plus AL_2O_3 plus Fe_2O_3 of the total compounds that make up the material. The Indian standard stated that for good pozzolans, the CaO content should be not be greater than 10%, and the in addition, the sum of SIO_2 plus AL_2O_3 should be greater than 50% [9]. Generally, amorphous silica reacts with calcium hydroxide more rapidly than does silica in the crystalline form [10].

Bulk chemical compositions and several comparative fundamental properties of both materials are listed in table 2 and 1 (Refer to section 4.0). The chemical properties of both AS residue and SF shows that the materials contain mainly SIO_2 and others in small percentage as can be seen in table 2. Table 1 shows some of the physical properties of both materials. The percentage amorphousness of AS residue is 71 while SF is 23. This shows the extent of formation of calcium silicate hydrate when ASR is used in concrete production. The amorphous characteristic (reactive property) makes ASR to have a very high pozzolanic property and therefore can be used to replace cement at a certain replacement level during concrete production. Amorphous Silica Residue (ASR) can be used where high compressive and flexural strength in concrete is required. The advantage of using the material in concrete is that it reduces the setting time of cement paste. Another advantage is that it can be used in a cold weather concreting. The disadvantage is that the concrete produced with it may have premature setting.

3.0 Methodology

Concrete mixtures with five levels of amorphous silica residue ranging from 5-30% and concrete mixtures with no amorphous silica residue were investigated to determine their effect on compressive and flexural strength. The mixtures were labeled M0, M5, M10, M20 and M30 with the different amorphous silica (SR) residue replacement percentages represented by the final digits in the label. The mixtures were proportioned for a target cube strength of 39N/mm^2 and had a cementitious material content of 320kg/m^3, a fine aggregate content of 615kg/m^3, a coarse aggregate content of 1260kg/m^3, and a water cement ratio of 0.48. The coarse aggregate used is granite and a clean river sand is used as fine aggregate. Both aggregates conforms to [11] and [12] respectively for coarse and fine aggregates, while the cement conforms to [13].

Tests to determine setting time, compressive and flexural strength were carried out in this study. For the tests, amorphous silica residue was used to replace 0 to 30% of cement by weight. For the compressive strength test, 150mm x150mmx150mm concrete cube specimen were used while 150mmx150mmx600mm beam moulds were used for flexural strength. A total of 75 specimens for concrete cubes and 75 specimens for concrete beams were cast and cured in water at room temperature in the laboratory for 3,7,28,60 and 90 days. At the end of each hydration period, three specimen for each were tested for compressive and flexural strength and the average recorded.

The setting time was determined in the laboratory using Vicat apparatus. For the control test (0% replacement), 200g of cement was used with 96g of water during the experiment to form a cement paste. The paste was then placed inside the Vicat mould and finally placed on the Vicat apparatus. Before the placement of the paste on the apparatus, the initial setting pin was fixed on the apparatus for the initial setting time. The apparatus is calibrated in millimeters. For the initial setting time, the initial setting pin was dropped on the paste to 5±1mm calibration mark on the apparatus. The initial setting time was then recorded starting from the time water was added to cement to the time the dropping of the pin was 5±1mm mark on the apparatus [14, 15].

Similarly, the final setting time was recorded using the final setting pin. The final setting time was taken when only the inner pin makes a mark on the paste when allowed to drop freely. The final setting time was then recorded starting from the time water was added to the cement to the time the inner pin of the final setting pin makes a mark on the paste. The experiment was repeated with 5%, 10%, 20% and 30% replacement of cement with amorphous silica residue.

4.0 Results and Discussions

Table 1 shows the result of the comparison of the amorphous silica residue and silica fume (Crystalline). The comparison was carried out in the Civil Engineering laboratory of the University of Nigeria, Nsukka.

Table 1: Comparison of Amorphous silica Residue and Silica Fume (Crystalline)

Properties	**AS Residue**	**SF (crystalline)**
Colour	White	Dark grey
Partial size (mm)	26	192
Specific surface Area (m^2/kg)	94700	23000
Pozzolanic Reactivity index (%)	88	30
Amorphousness (%)	71	23

Note: The comparison was carried out in the Civil Engineering Laboratory, University of Nigeria, Nsukka.

Table 2 shows the chemical analysis (characterization) of AS residue. The analysis was carried out in the Project Development Institute, Enugu State, Nigeria. The result shows that AS residues contain mainly SIO_2 (97.5%) and other oxides. P_2O_5 was not detected during the analysis. the analysis of silica fumes shoes also it contains mainly SIO_2 (95%) and other oxides. P_2O_5 was detected to be 1.1%.

Table 2: Chemical Analysis of AS and SF

Oxide (%)	**AS Residue**	**SF**
SIO_2	97.5	95
AL_2O_3	0.18	1.31
CaO	0.07	0.91
Fe_2O_3	0.05	0.18
MgO	0.12	0.39
Na_2O	0.74	0.19
K_2O	0.04	0.87
SO_4	1.3	-
P_2O_5	-	1.1

Note: The analysis was carried out in Project Development Institute, Enugu State, Nigeria.

The effect of AS residue on setting time can be seen in table 3, setting of the paste was accelerated by AS residue which results in the shortening of the setting time. The higher the setting time, the lower the strength of concrete and vice versa. For example, the time for initial and final setting of concrete with 30% AS residue was shortened to about 1½ that of the control test (0% replacement). the setting time of 5 – 30% replacement of cement with ASR ranges from

37-53mins and 408 – 573 for initial and final setting time respectively while the control test is 58mins and 580mins for initial and final setting time.

Table 3: Initial and final setting time of OPC/ASR paste

% Cement replacement	Initial setting time (mins)	Final setting time (mins)
0	58	580
5	53	573
10	49	522
20	46	496
30	37	408

The initial and final setting time of the control test (0% replacement) is 58mins and 580mins respectively; while 5-30% replacement of cement with amorphous silica residue ranges from 37-53mins for initial setting time and 408-573mins for the final setting time. The setting time decreases with the increase in the percentage replacement of cement with amorphous silica residue.

The compressive strength of concrete produced at each age (3,7,28,60 and 90 days) is shown in the tables 4-8 (Appendix-A) and that of the flexural strength is shown in table 9-13 (Appendix-B) compared to the control test, those made with AS residue showed greater strength both for the compressive and flexural strength respectively. The increasing strength was observed at curing periods as early as three days. Accelerated strength development started from seven days to ninety days for all concrete tested for both compressive and flexural strength.

In table 4, the compressive strength obtained when 100% cement (0% replacement) is used and cured at 3, 7, 28, 60 and 90days ranges from 10.56 – 26.04 N/mm^2. Table 5 shows that the compressive strength obtained by replacing cement with 5% of ASR ranges from 12.78 – 28.03N/mm^2 at the same hydration period. Table 6 shows the 10% replacement of cement with ASR. The result of the compressive strength ranges from 15.05 – 32.83 N/mm^2 while table 7 ranges from 18.64 – 35.16 N/mm^2 for 20% replacement of cement with ASR at 3, 7, 28, 60, and 90 days hydration period. The compressive strength of concrete obtained at 30% replacement of cement with ASR ranges from 23.69 – 38.16N/mm^2 at the same hydration period. Table 9 shows that the flexural strength of concrete obtained at 0% replacement of cement with ASR ranges from 2.14 – 7.80N/mm^2 while that of 5, 10, 20, and 30% replacement of cement with ASR in table 10, 11, 12 and 13 ranges from 2.29 – 8.12N/mm^2 , 2.92 – 10.20N/mm^2, 3.21 – 10.69 N/mm^2 and 4.16 – 11.69 N/mm^2 respectively for 3,7, 28,60 and 90 days hydration period.

The result of the compressive strength for 5-30%, replacement of cement with amorphous silica residue ranges from 12.78 – 38.16N/mm^2 while that of control test ranges from 10.86-26.64N/mm^2. The result shows that there is increase in the strength of concrete produced as the percentage replacement level of cement with amorphous silica residue increases.

Table 9-13 shows the result of the flexural strength of concrete with the same percentage replacement level of cement with amorphous silica residue. The result shows that flexural strength increases with increase in hydration period. The result of the flexural strength for 5-30%, replacement of cement with amorphous silica residue ranges from 2.29-11.69N/mm^2 while that of the control test ranges from 2.14-7.80N/mm^2.

The result shows that flexural strength also increases with increase in the replacement level of cement with amorphous silica residue (ASR).

5.0 Conclusions

The conclusion of this study can be summarized as follows:

a. Due to their high specific surface area and amorphous characteristics, amorphous silica residues have remarkably high pozzolanic activity and can be used as supplementary cementing materials.

b. With the addition of amorphous silica residues the setting time of the paste is shortened. This behaviour may be due to the early formation of a large amount of calcium silicate hydrate gel from hydration of tricalcium silicate and from the reaction between amorphous silica residues and calcium hydroxide.

c. The addition of amorphous silica residues can increase both the compressive and flexural strength of concrete produced.

d. The increased compressive and flexural strength may be due to the fact that calcium hydroxide diminished or wholly disappear and calcium hydrate increased with the addition of the amorphous silica residues.

e. Strength development in concrete increases with increase in hydration period.

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APPENDIX-A

Table 4: Result of compressive strength obtained with 0% replacement of cement with amorphous silica residue

Cube size (mm)	Age of Cube(days)	Test load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
150x150x150	3	248	11.02	
150x150x150	3	215	9.56	10.86
150x150x150	3	270	12.00	
150x150x150	7	341	15.16	
150x150x150	7	330	14.67	14.64
150x150x150	7	317	14.09	
150x150x150	28	378	16.80	
150x150x150	28	426	18.93	17.58
150x150x150	28	383	17.02	
150x150x150	60	401	17.82	
150x150x150	60	490	21.78	19.87
150x150x150	60	450	20.00	
150x150x150	90	500	22.22	
150x150x150	90	570	25.33	26.04
150x150x150	90	688	30.58	

Table 5: Result of compressive strength obtained with 5% replacement of cement with amorphous silica residue

Cube size (mm)	Age of Cube(days)	Test load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
150x150x150	3	273	12.13	
150x150x150	3	315	14.00	12.78
150x150x150	3	275	12.22	
150x150x150	7	340	15.11	
150x150x150	7	300	13.33	14.67
150x150x150	7	350	15.56	
150x150x150	28	426	18.93	
150x150x150	28	406	18.04	18.83
150x150x150	28	439	19.51	
150x150x150	60	409	18.18	
150x150x150	60	500	22.22	22.18
150x150x150	60	588	26.13	
150x150x150	90	496	22.04	
150x150x150	90	684	30.40	28.03
150x150x150	90	712	31.64	

Table 6: Result of compressive strength obtained with 10% replacement of cement with amorphous silica residue

Cube size (mm)	Age of Cube(days)	Test load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
150x150x150	3	350	15.56	
150x150x150	3	299	13.29	15.05
150x150x150	3	367	16.31	
150x150x150	7	413	18.36	
150x150x150	7	501	22.27	19.84
150x150x150	7	425	18.89	
150x150x150	28	530	23.56	
150x150x150	28	591	26.27	24.31
150x150x150	28	520	23.11	
150x150x150	60	596	26.49	
150x150x150	60	549	24.40	26.07
150x150x150	60	615	27.33	
150x150x150	90	694	30.84	
150x150x150	90	789	35.07	32.83
150x150x150	90	733	32.58	

Table 7: Result of compressive strength obtained with 20% replacement of cement with amorphous silica residue

Cube size (mm)	Age of Cube(days)	Test load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
150x150x150	3	442	19.64	
150x150x150	3	396	17.60	18.64
150x150x150	3	420	18.67	
150x150x150	7	480	21.33	
150x150x150	7	500	22.22	21.55
150x150x150	7	475	21.11	
150x150x150	28	580	25.78	
150x150x150	28	630	28.00	26.30
150x150x150	28	565	25.11	
150x150x150	60	682	30.31	
150x150x150	60	720	32.00	32.77
150x150x150	60	810	36.00	
150x150x150	90	800	35.56	
150x150x150	90	897	39.87	35.16
150x150x150	90	676	30.04	

Table 8: Result of compressive strength obtained with 30% replacement of cement with amorphous silica residue

Cube size (mm)	Age of Cube(days)	Test load (kN)	Compressive strength (N/mm^2)	Average compressive strength (N/mm^2)
150x150x150	3	540	24.00	
150x150x150	3	549	24.40	23.69
150x150x150	3	510	22.67	
150x150x150	7	580	25.78	
150x150x150	7	591	26.28	27.43
150x150x150	7	680	30.22	
150x150x150	28	690	30.67	
150x150x150	28	578	26.69	29.49
150x150x150	28	700	31.11	
150x150x150	60	820	36.44	
150x150x150	60	760	33.78	36.74
150x150x150	60	900	40.00	
150x150x150	90	905	40.22	
150x150x150	90	784	34.80	38.16
150x150x150	90	888	39.47	

APPENDIX-B

Table 9: Result of flexural strength obtained with 0% replacement of cement with amorphous silica residue

Bean size (mm)	Age of beam (days)	Test load (kN)	Modulus of rupture (N/mm^2)	Average modulus of rupture (N/mm^2)
150x150x600	3	8.52	1.54	
150x150x600	3	12.84	2.28	2.14
150x150x600	3	14.68	2.61	
150x150x600	7	18.90	3.36	
150x150x600	7	18.60	3.31	3.20
150x150x600	7	16.56	2.94	
150x150x600	28	35.00	6.22	
150x150x600	28	26.88	4.78	5.43
150x150x600	28	29.80	5.30	
150x150x600	60	35.10	6.24	
150x150x600	60	41.00	7.29	6.52
150x150x600	60	34.00	6.04	
150x150x600	90	44.40	7.89	
150x150x600	90	45.10	8.02	7.80
150x150x600	90	42.10	7.48	

Table 10: Result of flexural strength obtained with 5% replacement of cement with amorphous silica residue

Bean size (mm)	Age of beam (days)	Test load (kN)	Modulus of rupture (N/mm^2)	Average modulus of rupture (N/mm^2)
150x150x600	3	12.88	2.29	
150x150x600	3	11.00	1.96	2.29
150x150x600	3	14.80	2.63	
150x150x600	7	16.90	3.00	
150x150x600	7	14.50	2.58	2.86
150x150x600	7	16.91	3.01	
150x150x600	28	35.66	6.34	
150x150x600	28	31.00	5.51	5.91
150x150x600	28	33.10	5.88	
150x150x600	60	39.80	7.16	
150x150x600	60	42.80	7.61	7.37
150x150x600	60	41.30	7.34	
150x150x600	90	50.00	8.88	
150x150x600	90	47.00	8.36	8.12
150x150x600	90	40.00	7.11	

Table 11: Result of flexural strength obtained with 10% replacement of cement with amorphous silica residue

Bean size (mm)	Age of beam (days)	Test load (kN)	Modulus of rupture (N/mm^2)	Average modulus of rupture (N/mm^2)
150x150x600	3	15.10	2.68	
150x150x600	3	15.60	2.77	2.92
150x150x600	3	18.70	3.32	
150x150x600	7	18.96	3.37	
150x150x600	7	23.00	4.09	4.04
150x150x600	7	26.20	4.66	
150x150x600	28	41.00	7.29	
150x150x600	28	39.30	6.99	7.01
150x150x600	28	38.00	6.76	
150x150x600	60	49.30	8.76	
150x150x600	60	43.00	7.64	8.19
150x150x600	60	46.00	8.18	
150x150x600	90	56.10	9.97	
150x150x600	90	55.00	9.78	10.20
150x150x600	90	61.00	10.84	

Table 12: Result of flexural strength obtained with 20% replacement of cement with amorphous silica residue

Bean size (mm)	Age of beam (days)	Test load (kN)	Modulus of rupture (N/mm^2)	Average modulus of rupture (N/mm^2)
150x150x600	3	15.80	2.81	
150x150x600	3	19.60	3.48	3.21
150x150x600	3	18.80	3.34	
150x150x600	7	22.40	3.92	
150x150x600	7	28.00	4.98	4.14
150x150x600	7	19.80	3.52	
150x150x600	28	40.76	7.25	
150x150x600	28	44.10	6.95	7.08
150x150x600	28	39.60	7.04	
150x150x600	60	49.70	8.84	
150x150x600	60	54.00	9.60	9.39
150x150x600	60	54.80	9.74	
150x150x600	90	59.60	10.60	
150x150x600	90	57.00	10.13	10.69
150x150x600	90	63.80	11.34	

Table 13: Result of flexural strength obtained with 30% replacement of cement with amorphous silica residue

Bean size (mm)	Age of beam (days)	Test load (kN)	Modulus of rupture (N/mm^2)	Average modulus of rupture (N/mm^2)
150x150x600	3	23.10	4.11	
150x150x600	3	25.30	4.50	4.16
150x150x600	3	21.80	3.88	
150x150x600	7	36.20	6.44	
150x150x600	7	39.70	7.06	6.76
150x150x600	7	38.10	6.77	
150x150x600	28	47.20	8.39	
150x150x600	28	41.00	7.29	8.21
150x150x600	28	50.30	8.94	
150x150x600	60	52.96	9.42	
150x150x600	60	53.00	9.42	9.63
150x150x600	60	56.60	10.06	
150x150x600	90	61.30	10.90	
150x150x600	90	67.00	11.91	11.69
150x150x600	90	68.90	12.25	