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Durability of Silica Sand-Based Self-Compacting Mortar: A Study on Sorptivity and Chemical Attack

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Abstract

Cement is an essential construction material which serves as the binder in the production of concrete, mortar and bricks production. The production of cement poses a serious issue as it results in the emission of greenhouse gases directly responsible for climate change. In this study, Self-Compacting Mortar (SCM) mixes were developed by incorporating Ground Silica Sand (GSS) of 0 - 10% at a step of 2.5% and Raw Ground Silica Sand (RSS) of 0 - 100% at a step of 25% as replacement for cement and fine aggregate, respectively. The sorptivity and chemical attack via the use of Sodium Chloride (NaCl) on SCM specimens produced from different mixes were determined after 28 and 56 days of curing. The sorptivity of SCM specimens increased at all levels compared to the control when RSS is used as replacement for fine aggregate while the same was experienced when GSS was used as replacement for cement except at the 5% replacement level. All specimens fell under the ASTM standard for sorptivity states that all construction materials must have a water absorption value within 20%. When exposed to chemical attacks, there was an increase in weight loss and compressive strength loss with every increase in percentage replacement while the SCM does not deteriorate rapidly after exposure to NaCl. It can be concluded that GSS and RSS exhibited the potential for application as binder and sand contents in SCM production.

Keywords: Cement, Chemical Attack, Self-Compacting Mortar, Silica sand, Sorptivity

1 Introduction

The mixture of cement, sand, and water known as cement mortar is frequently used in construction to lay bricks and blocks, plaster walls and ceilings, and for other purposes [1]. Mortar is produced extensively worldwide and its use is strongly related to the global construction sector [2]. It is composite material which is produced from the mixture of cement, fine aggregate and water. The characteristics that distinguish Self-Compacting Concrete (SCC) from regular concrete can be attributed largely to those exhibited by the mortar it contains, while the presence of aggregate in it contributes less.

Self-Compacting Mortar (SCM) is a mortar type that incorporates chemical admixtures in addition to other constituents used in the production of normal mortar and acts exactly like the mortar presence in SCC. SCC is a type of concrete that can flow under its own weight and be placed in formwork with congested reinforcement without requiring vibration while maintaining uniformity. Among the benefits of SCC are quicker construction, reduced site manpower, better surface finishing, relatively simple placement, and enhanced durability [3]. Developing SCM with improved characteristics is critical in the production of SCC that meet the relevant standard requirements [4].

Both SCM and SCC employed high cement contents to achieve the desired self-consolidation characteristics, giving them an advantage over normal concrete. However, cement has great impact on the environment as it is a major source of carbon dioxide emission which contributes to climate change [5]. The activities related to extraction of non-renewable resources such as natural sand creates negative environmental impacts with increasing risk of ecological imbalance such habitat destruction, flooding, erosion. In addition, the priceless resources run the risk of running out if they are continuously harvested.

Consideration of alternative materials as alternative to cement and fine aggregate in mortar and concrete production is gaining popularity because of the needs to conserve resources as well as reduce the negative impacts of cement production and these factors have influenced numerous studies on the utilization of alternative materials which production techniques make use of renewable energy sources and emit fewer emissions in SCM and SCC. Over the years, experimental studies have been conducted by replacing some of the components (cement or fine aggregate) of mortar and concrete with materials such as seashells, metakaolin, recycled glass, red wood, recycled aggregate concrete, waste plastics, silica sand [6].

Previous studies have in the past applied silica sand as constituents of mortar and concrete. [7] established that silica sand is appropriate for usage as replacement for fine aggregate with improved the mechanical characteristics. [8] used silica sand as partial replacement of fine aggregate in concrete. It was found that the maximum compressive strength was achieved at 15% of fine aggregate replacement with sand in concrete. [9] explored the possibility of replacing cement with silica sand in concrete. The study revealed that silica sand (up to 12%) can effectively serve as partial replacement of cement in concrete without compromising the strength of concrete. [10] investigated the influence of nano silica sand addition as cement replacement in cement mortar and found that the mortar workability decreased while the compressive and flexural strength was increased with the addition of nano silica sand. The reported studies have shown that silica served have found applications in normal cement mortar and concrete. However, its application in SCM is not yet documented. This study evaluates the durability properties of SCM incorporating Silica Sand as Binder and Fine Aggregate Contents.

2 Material and Methods

2.1 Materials

In this study, sharp sand served as fine aggregate and was collected from riverbanks within Osogbo, Nigeria. Dangote 3X Portland Limestone Cement, CEM II 42.5N (A-L) was used as binding material. It was obtained from a retail store within Osogbo, Osun State, Nigeria. The locally available silica sand free from clayey matters was sourced from Owo Eba, Osogbo, Nigeria (Lat: 7° 43’ 44.83” N, Long: 4° 34’ 49.30” E) and the chemical composition of silica sand is shown in Table 1. The silica sand was used as supplementary cementitious material and fine aggregate contents in this study. Conplast SP 430 was used as chemical admixture (Superplasticizer) to achieve the workability recommended by [3] for fresh self-compacting mortar (SCM). It was sourced from a retailing store within Osogbo, Osun State. Potable water was employed in mixing and curing of all materials which conforms to [11]. The water was collected from the laboratory at Osun State University. The particle size distribution of our materials is shown in Fig 1.

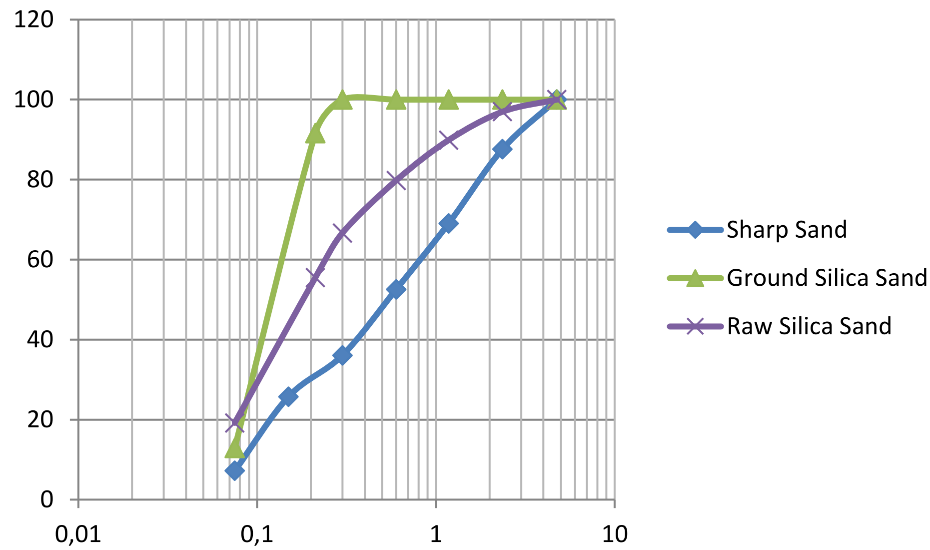

Figure 1. Particle size distribution for materials

Table 1. Chemical Composition of Silica Sand

Chemical Constituents	Compositions (%)
SiO_2	95.39
Al_2O_3	2.13
Fe_2O_3	1.87
CaO	0.20
SO_3	0.01
Mg_2O	0.02
MgO	1.53
K_2O	0.36
TiO_2	0.89
$SiO_2 + Al_2O_3 + Fe_2O_3$	99.39

2.2 Chemical Composition

The summary of the detailed chemical composition of silica sand is presented in Table 2. The main compounds present in RSS and GSS are Silica (SiO2), iron oxide (Fe2O3) and alumina (Al2O3) with the values of 95.39, 1.87 and 2.13 for RSS and 68.82, 18.461, and 4.337 for GSS. The addition of these three compounds is 99.39% for RSS and 91.622% of GSS. In [12], the minimum value for the sum of these three oxides is specified as 70%. Although both RSS and GSS are found to be enriched in silicates, they contain limited amounts of lime, sulphate, magnesia, sodium oxide, potassium oxide and titanium dioxide. The main compositional difference between RSS and GSS is in terms of the RSS having a higher content of SiO2 but lower Al2O3, Fe2O3 and Na2O + 0.659 K2O than GSS while GSS have no composition of sodium oxide (Na2O) and sulfur trioxide (SO3).

Table 2. Chemical Composition of Silica Sand

Chemical Constituents	Compositions (%)	
	RSS	GSS
SiO_2	95.39	68.82
Al_2O_3	2.13	18.461
Fe_2O_3	1.87	4.337
CaO	0.20	0.722
SO_3	0.01	-
Na_2O	0.02	-
MgO	1.53	0.219
K_2O	0.36	3.410
TiO_2	0.89	1.591

$Na_2O + 0.659\ K_2O$	0.38	3.410
$SiO_2 + Al_2O_3 + Fe_2O_3$	99.39	91.622

2.3 SCM mix proportion and specimens preparation

Mix proportion of 1:2.2 (cement: sand) with fixed water/cement ratio of 0.50, total binder content 676 kg/m^3, Conplast SP 430 of 8.11 kg/m^3 were used to prepare the mortar mixes. The first five SCM batches were prepared using ground silica sand to replace cement at five different replacement levels (0, 2.5%, 5%, 7.5% and 10%) by weight. The second five SCM batches were prepared by replacing sharp sand using silica sand at five different percentage replacements (0, 25%, 50%, 75% and 100%) by weight. The mixture proportions of the various mortar mixes for the replacement of fine aggregate and cement are summarized in Tables 3(a-b)

Table 3a. Mix design for mortar with GSS as substitute for cement (1 kg/m^3)

Mix ID	GSS (%)	Cement (kg)	GSS (kg)	Sand (kg)	Water (kg)
1	0	676	0	1487	338
2	2.5	659.1	16.9	1487	338
3	5.0	642.2	33.8	1487	338
4	7.5	625.3	50.7	1487	338
5	10.0	608.4	67.6	1487	338

Table 3b. Mix design for mortar with RSS as substitute for sharp sand (1 kg/m^3)

Mix ID	RSS (%)	Cement (kg/m^3)	RSS (kg)	Sand (kg)	Water (kg)
1	0	676	0	1487	338
2	25	676	371.75	1115.25	338
3	50	676	743.5	743.5	338
4	75	676	1115.25	371.75	338
5	100	676	1487	0	338

2.4 Testing Methods

The workability of the fresh mortar mixes was studied by measuring the slump values of fresh mortar, with the temperature being monitored with the use of a thermometer before pouring the steel molds. The mini-slump flow test was used for determining the workability and consistency of fresh SCM as stated in the [3]EFNARC (2005) and the V-funnel flow test was used to assess the workability and consistency of fresh SCM. The sorptivity coefficient of specimens was obtained by capillary water absorption test carried out according to [13]. The chemical attack to observe the specimens resistance to sodium chloride were carried out according to [14].

3 Results and Discussions

3.1 Durability properties of SCMs

The durability properties of the hardened mortar were examined through carrying out the sorptivity tests alongside the chemical attack tests aged 28 and 56 days.

3.1.1 Sorptivity Test

The sorptiivity coefficient results are shown in Fig. 2(a-b). ASTM standard for sorptivity states that all construction materials must have a water absorption value within 20% and all our replacement levels fall within that standard. The results show that the sorptivity values ranged from 1.65 to 4 mm/h$^{1/2}$ for SCM with 0 to 10% GSS and ranged from 1.85 to 7 mm/h$^{1/2}$ for SCM with 0 to 100% RSS, respectively. The sorptivity results increases by percentage replacement with both GSS and RSS experiencing a slight drop at 2.5% and 5% GSS content, with effects more prominent with RSS replacement. The 10% GSS replacement mix shows the highest sorptivity observed with 5% recording the lowest but close to the control mix and the 100% RSS replacement mix recorded the highest sorptivity with 25% recording the lowest sorptivity but closest to the control mix. Tables 4(a-b) shows the soprtivity value compared with standard deviation.

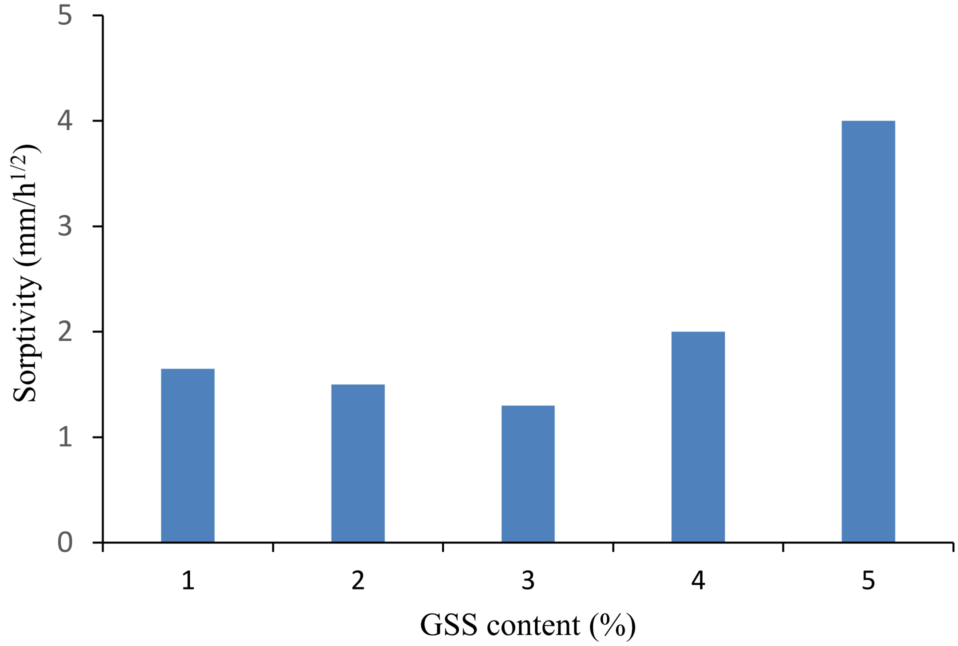

Figure 2a. Sorptivity of SCM with GSS as replacement for cement

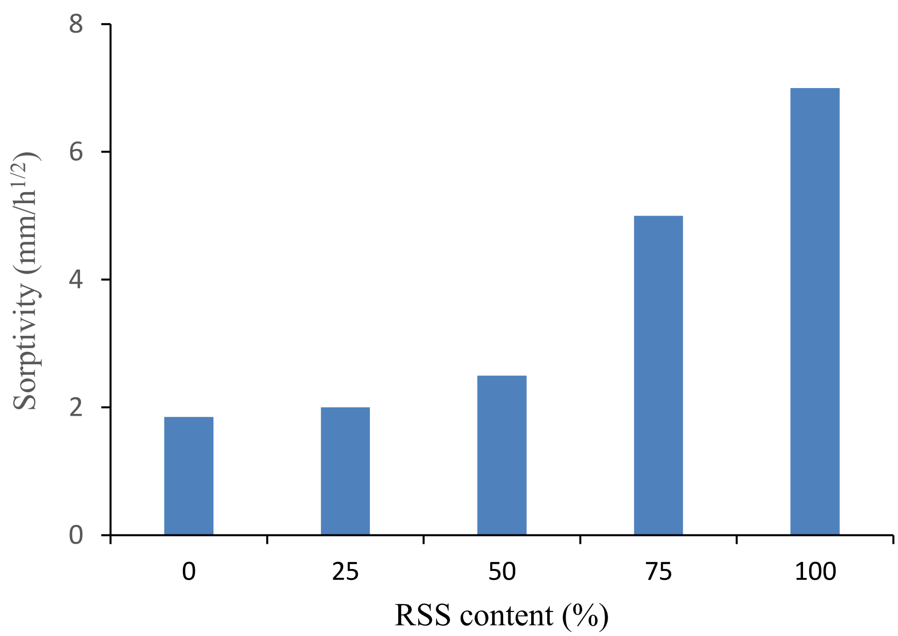

Figure 2b. Sorptivity of SCM with RSS as replacement for fine aggregate

Table 4a. Chemical Attack with NaCl on SCM with GSS

Sample Mix ID (%)	Sorptivity ($mm/h^{1/2}$)	Sorptivity ($mm/h^{1/2}$) mean ± SD
0	1.65	1.65 ± 0.18
2.5	1.80	1.80 ± 0.15
5.0	1.78	1.78 ± 0.16
7.5	2.59	2.59 ± 0.22
10	4.00	4.00 ± 0.19

Table 4b. Chemical Attack with NaCl on SCM with GSS

Sample Mix ID (%)	Sorptivity ($mm/h^{1/2}$)	Sorptivity ($mm/h^{1/2}$) mean ± SD
0	1.85	1.85 ± 0.17
25	2.75	2.75 ± 0.15
50	4.20	4.20 ± 0.19
75	5.30	5.30 ± 0.20
100	7.00	7.00 ± 0.21

3.1.2 Chemical Attack

The weight loss and compressive strength loss results of hardened SCM due to chemical attack using NaCl are indicated in Table 4(a-b). The test follows [15] which provides standard test methods for chemical resistance of mortar. The results showed that the weight loss for GSS ranged from 0.96 to 2.14% while also experiencing a compressive strength loss ranging from 4.67 to 9.25% and the weight loss for RSS ranged from 1.25 to 2.11% while also experiencing a compressive strength loss for RSS ranging from 3.81 to 9.68%. The weight loss experienced a gradual increase as GSS replacement increased and the same was experienced with the RSS replacement. The compressive strength loss also experienced a gradual increase with both GSS and RSS replacement. The SCM does not deteriorate rapidly when exposed to NaCl.

Table 5a. Chemical Attack with NaCl on SCM with GSS

Sample Mix ID (%)	Weight Loss (%)	Compressive Strength Loss (%)	Compressive Strength Loss (%) mean ± SD
0	0.96	4.37	4.37 ± 0.30
2.5	1.38	3.03	3.03 ± 0.25
5.0	1.69	3.05	3.05 ± 0.27
7.5	1.98	5.46	5.46 ± 0.33
10	2.14	9.25	9.25 ± 0.35

Table 5b. Chemical Attack with NaCl on SCM with RSS

Sample Mix ID (%)	Weight Loss (%)	Compressive Strength Loss (%)	Compressive Strength Loss (%) mean ± SD
0	1.25	3.81	3.81 ± 0.27
25	1.74	4.76	4.76 ± 0.40
50	1.98	7.98	7.98 ± 0.45
75	1.90	6.54	6.54 ± 0.33
100	2.11	9.68	9.68 ± 0.38

3.2 Comparison with other SCM modifiers

Table 6 shows the comparison between SCM made with silica sand as a modifier compared to other modifiers, it compares their durability results (sorptiity and chemical attack). Ground silica sand mortars (1.65–4.00 mm/h$^{(1/2)}$ sorptivity, 0.96–2.14% weight loss, 4.37–9.25% strength loss) match or surpass other SCMs while fly ash, metakaolin, and silica fume offer sorptivity ranges between 3.5–6.5 mm/h$^{\{1/2\}}$ and chemical attack weight losses between 1.0–2.2%, with silica fume exhibiting the lowest strength loss at 2.5–5.0%. The modified self-compacting mortars modified with silica sand, fly ash, and metakaolin all exhibit increased durability through significantly reduced sorptivity and resistance to chemical attack.

Table 6. SCM Modifiers and Durability Comparisons

SCM Modifier	Sorptivity (mm/h$^{\{1/2\}}$)	Weight loss (%)	Strength loss (%)	Source
Silica Sand (GSS and RSS)	1.65–7.00	0.96–2.14	3.81–9.68	
Fly Ash	3.8–6.5	<2.0	<6.0	[16]
Metakaolin	3.5–4.2	1.4–2.2	3.5–6.5	[17]
Silica fume	3.5–4.1	1.0–2.0	2.5–5.0	[16]

4 Conclusion

Based on the findings from the study, a conclusion can be drawn. GSS and RSS exhibited the potential for application as binder and sand contents in SCM production. The weight loss for GSS ranged from 0.96 to 2.14% while also experiencing a compressive strength loss ranging from 4.67 to 9.25% and the weight loss for RSS ranged from 1.25 to 2.11% while also experiencing a compressive strength loss for RSS ranging from 3.81 to 9.68%. The sorptivity values ranged from 1.65 to 4 mm/h$^{1/2}$ for SCM with 0 to 10% GSS and ranged from 1.85 to 7 mm/h$^{1/2}$ for SCM with 0 to 100% RSS, respectively. GSS replacement 10% for cement and 25% RSS replacement for sharp sand are adequate for the production of SCM. GSS and RSS also exhibited the potential for binder and fine aggregate content in SCM production.

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