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Research Paper

Influence Of Nano Silica Quantity on The Strength and Abrasion Properties of Cement Mortar Containing Agro Waste Ashes

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Abstract
Massive volumes of cement are needed for urbanization and infrastructure development in Sub-Saharan Africa. Some ashes of agro wastes are pozzolanic. Notable pitfalls of pozzolans in cement composites include poor early age properties and susceptibility to abrasion. Nanoparticles are reportedly helpful in mitigating some challenges. Influence of Nano Silica (NS) on cement mortar with Rice Husk Ash (RHA) and Groundnut Shell Ash (GSA) was explored. Rice husks and groundnut shells were calcined at 700℃ and 600℃ for RHA and GSA, respectively. RHA was used to produce NS. Sand/binder ratio was 3:1 and water/binder 0.5. NS (0, 0.5, 1 and 1.5%), GSA (0, 7.5 and 10), and RHA (0, 5, 10, and 15%) replaced cement. Additives were tested for particle size, specific surface areas, and chemical composition. Mortar workability was assessed. Mortar cubes were cured, tested for compressive strength (7, 28, 56, and 90 days) and abrasion loss at 90 days. NS had the lowest particle size (46 nm), largest specific surface area (72 m2/g), and 89% for the sum of SiO2, Al2O3, and Fe2O3 while RHA and GSA were 78 nm, 42 m2/g, 81% and 94 nm, 43 m2/g, 27%, respectively. 0.5%NS enhanced early age strength, though upswing in NS beyond 10% content depreciates the compressive strength. 0.5% NS gave higher abrasion resistance than the control and all other mixes with higher NS content. Conclusively, NS quantity influences mortar properties.

Keywords: *Nano silica, Pozzolans, Susceptibility, Abrasion, Specific surface area*

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I. INTRODUCTION

More binders will be demanded in the construction industry in the nearest futures due to the speedy pace of urbanization and development in the sub-Saharan Africa. The construction sector is devoting enormous effort to discovering and encouraging the use of less or no cement by partially or fully replacing cement with materials that are eco-friendly, have low energy demand, easy to apply and are readily available [1], [2].

[3] reported that the current advances and application of nanotechnology in the formulation of cement-based materials is gaining popularity in the construction sector. Nano particles are useful materials with many outstanding properties. The most commonly used Nano material is the silica nanoparticle. Nano Silica (NS) is the most popular choice among researchers and developers to be incorporated as additive in paste, mortar, and concrete. The exceptional properties of NS include the large specific surface area, extremely fine particle size, and its interfacial effects in composites. Furthermore, numerous materials, particularly the ashes derived from certain agro wastes, have been validated as beneficial supplementary cementitious materials (SCM); however, it is important to note that not all of them qualify as pozzolans. The performance of SCMs in terms of reactivity is influenced by various factors, including silica content, alumina concentration, excess calcium hydroxide (CH), specific surface area, and particle size [6]. RHA exhibits notable pozzolanic reactivity attributed to its elevated silica oxide content [7]. This material is typically produced through the calcination of rice husk, which is a byproduct of rice processing. GSA is produced through the combustion of peanut husks. Nonetheless, the macro characteristics of RHA and GSA typically allow for the development of a porous and less dense matrix in the composites derived from them. Nonetheless, the incorporation of NS alongside such ashes affects the engineering properties. Previous investigations have shown that the incorporation of NS into cement typically leads to

significant enhancements in the mechanical and durability characteristics of composites. Numerous reports indicate that NS serves as an effective alternative for reducing cement consumption [8], [9].

[10] observed a 30 percent increase in compressive strength compared to the control sample at a curing age of 3 days with the incorporation of 2% NS. Additionally, Du et al., (2014) noted that concrete samples containing 0.4 % and 0.8 % NS achieved compressive strength increases of 10 % and 13 % respectively compared to the control sample. The effect was attributed to the impact of nano-fillers and pozzolanic reactivity. It has been observed that an excessive amount of NS beyond the optimal level leads to a reduction in compressive strength, attributed to flocculation and agglomeration phenomena. One could propose that the flocculation of small NS particles may have led to the formation of weak areas in concrete. [12] indicated that NS led to a decrease in the porosity of concrete, which in turn reduced water absorption and enhanced durability.

Nevertheless, there is limited information regarding the impact of NS quantity on the abrasion of cement mortars incorporating agro waste ashes. This study examines how the quantity of NS affects the strength and abrasion characteristics of cement mortar that incorporates RHA and GSA.

II. MATERIALS AND METHODS

The engineered mortars investigated in this work were produced by mixing river sand, cement, rice husk ash, groundnut shell ash, silica nanoparticles, and potable water from a borehole. The river sand used was well graded dry fine grained sand with less than 5 % retention on the 75 micron sieve and its fineness modulus was calculated to be 1.80. Therefore, the sand was appropriate for mortar production. Portland limestone cement (32.5N) produced in Nigeria was used. The entire cement required for the study was acquired in one batch from the local construction market in Ado Ekiti. The cement was only one week old from date of production as indicated on the packaging bag.

Rice husk ash (RHA) was obtained by burning rice husks from Igbemo - Ekiti at a control temperature of 700°C in a furnace at the Department of Science Technology, the Federal Polytechnic, Ado-Ekiti. The ash was further grinded and sieved with the 75 micron standard sieve. In similar vein, the groundnut shell ash was obtained by calcining dry groundnut husks to ash at a temperature of 600°C in a furnace at the location mentioned above. Also, the ash was grinded and sieved to get finer ash for the laboratory experiments. The silica nanoparticles were synthesized from RHA using precipitation and sol-gel methods. RHA was mixed with sodium hydroxide solution, heated and filtered. Hydrochloric acid was gradually added to the filtrate, sol-gel was formed, washed severally with distil water, filtered and was finally dried to obtain the white fine Nano silica particles. Some personal safety precautions were taken during the production and application of the NS.

Department of Environment (DoE) method was employed in preparing the mix design. A mixing ratio of binder: sand (1:3) and water binder ratio 0.5 was utilized. The preliminary tests performed on the materials were: particle size distributions, specific surface areas and chemical composition. The tests were done at the National Steel Raw Materials Explanation Agency Kaduna, Kaduna state. Cement was partially replaced with 0%, 0.5%, 1%, and 1.5% NS; 0, 7.5and 10% GSA and 0, 5, 10, and 15% RHA.

In preparing the mortar, the river sand was initially poured on a clean flat solid surface; the binder components (cement, NS, GSA, and RHA) were batched according to the mix proportion calculated, these were thoroughly dry mixed for few minutes. Superplasticizer was to improve the workability and the water was gradually poured while mixing continued till the water was fully poured and the mixing was thorough. Conventional manual mixing method was used for the work. Workability of fresh mortars was determined using the slump cone. Freshly mixed mortar was scooped and compacted in two layers into the moulds that had been oiled to avoid sticking of materials to the surface. After compaction, the surfaces of the mortar-filled moulds were smoothed and scraped off. The mortar-filled moulds were covered with polythene sheet for 24 hours and left intact in the laboratory. Cast mortar cubes were cured by full immersion in water and tested for compressive strength at 7, 28, 56 and 90 days and abrasion loss at 90 days.

III. RESULTS AND DISCUSSION

3.1 *Preliminary results*

The results of the preliminary tests done on the binders are shown in Table 1. The specific surface areas of the NS, GSA and RHA as determined using the BET method are 72, 43 and 42 m^2 /g, respectively. NS is observed to have the highest specific surface area than the other materials in the binding components. This predicts that the NS will most likely be more reactive than the others by creating extra active sites for increased reactivity and thus enhancing some of the properties and performances. [13] reported improved reactivity of silica nanoparticles with large specific surface area.

The particle sizes of the materials are 46, 94 and 78 nanometres for NS, GSA and RHA, respectively. The miniscule particle size of the NS compared to the others can influence its reactivity. NS is found to have a lower specific gravity than cement and RHA which are 3.1 and 2.2, respectively. This may inform a modification of the density of the resulting composites. All the binding components are in powder form and the colours range from white to diverse shades of grey colour.

Table 1. Preliminary tests results on the binder components

Property	Cement	NS	GSA	RHA
Specific surface area (m^2 /g)		72	43	42
Particle size (nm)		46.36	94.14	78.11
Specific gravity	3.12	2.06	1.81	2.2

3.2. Chemical composition

Table 2 presents the chemical composition of the binders used in preparing the mortar. The values were obtained using X-ray fluorescence (XRF) method. *ASTM C618-19* states that, for a material to be pozzolanic, the addition of the three major oxides (SiO_2 +Al_2O_3 + Fe_2O_3) in such material must not be less than 70 percent. Considering the results depicted in Table 3, Nano silica has 88.8 %, GSA has 27% and RHA has 81.2%. The indication is that both NS and RHA are very reactive pozzolans while GSA does not belong to the pozzolan family, [16], [17] elaborated on the pozzolanic reactivity of both NS and RHA.

However, [2] suggested that GSA can find usefulness as a filling supplementary cementitious material if it is combined with very fine pozzolanic materials. Comparing the SiO_2 content of each of the binder components, NS has the highest SiO_2 content which is a pointer to its tendency for high reactivity

Table 2: Chemical compositions of the binders

Oxide Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	MnO
Nano silica	86.5	2.2	0.1	0.6	0.0	0.0	0.35	0.03
GSA	18.5	4.8	3.7	20.9	5.1	2.4	12.8	0.9
RHA	76.9	2.6	1.7	4.8	0.0	2.0	4.5	0.4
Cement	20.1	5.8	2.4	64.0	1.2	3.5	0.8	0.4

3.3. Workability

The workability of the engineered mortars as measured by the slump test is presented in Figure 1. The values obtained are between 0 and 36 mm. Control mortar mix had a slump value of 26.5 mm, the two mixes containing binary binders (cement and GSA) gave higher values than control . Addition of GSA is observed to the increase workability of the two mixes mentioned. In all, mortar Mix (G10) gave the highest slump value. All mixes incorporating NS had poorer workability than the control or those with binary binders. This is as a result of the zero slumps they recorded. The reduced slump values for cement mortars containing the combination of NS, GSA and RHA may be attributed to the higher specific surface areas of the materials especially the silica Nano particles.

[19] reported a similar reduction in the workability of concrete containing Nano-silica. They connected the observation to the high surface area and the unsaturated bond in Nano-silica. They indicated that higher water content is required to make concrete more workable.

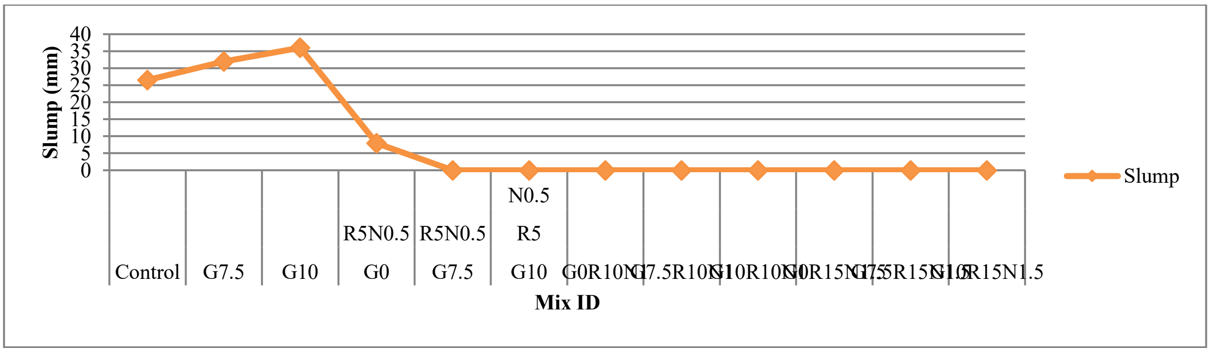

Figure 1. Slump of cement mortars containing NS, GSA and RHA

3.4. Compressive strength

Figure 2 illustrates the compressive strength of the twelve mortar mixes examined in this study. The findings from the curing periods of 7, 28, 56, and 90 days are presented. The findings indicate that the compressive strengths of all mortar mixes exhibited improvement with an increase in the duration of curing, regardless of the material compositions and proportions used. For instance, the G7.5 mix exhibited strengths of 5.31, 9.53, 10.33, and 13.4 N/mm2 at 7, 28, 56, and 90 days, respectively, whereas the G0R15N1.5 mix demonstrated strengths of

5.8, 10.27, 11.53, and 20.4 N/mm^2 at the same intervals. This observation can be linked to the ongoing hydration of cementitious components facilitated by curing conditions.
At the early age of 7 days, the control mortar recorded higher compressive strength than G7.5 and G10 which are the two mixes containing binary binder i.e. cement and an agro waste ash type. This observation is a testimonial that most SCMs and pozzolans do have poor early strength properties. [19] reported similar observation in which the early age strength of composites containing pozzolans are lower than that of mixtures containing 100% cement. However, mortar mixes incorporating 0.5 % NS gave higher strength than the control and other mixes with higher NS content. The same scenario persisted at 28 days of curing adding that mix G7.5R10N1 also exceeded the control mix in performance.

Furthermore, mortar mixes G10, R10N1, G7.5R10N1, G0R15N1.5 and most especially, all mixes containing 0.5% NS, all exceeded the control mix at the later ages 56 and 90 days. These higher compressive strengths at the later ages is attributable to the effect of pozzolanic reaction especially when the highly reactive pozzolans especially the NS and RHA particles react with calcium hydroxide to form calcium-silicate-hydrate. Appreciable high compressive strengths were recorded by all mortar mixes containing Nano silica except for mixes G10R10N1, G7.5R15N1.5 and G10R15N1.5. The performance of the Nano silica mortars is connected with the filling ability of the very tiny fine NS particles filling up pores and voids in the mortar and thus enhancing the strength. However, the extremely poor strengths exhibited by mixes G10R10N1, G7.5R15N1.5 and G10R15N1.5 at both early and later ages can be due to dilution effect caused by a high percentage of the SCMs (GSA, RHA and NS) replacing cement in the mixes. The poor performance can also be attributed to the agglomeration caused by high NS particle content (beyond the optimum) in the mixes. The mortar mix G10R5N0.5 demonstrated superior compressive strength across all ages examined. Specifically, the compressive strengths of mix G10R5N0.5 were found to be 73%, 40%, 36%, and 65% greater than those of the reference mortar at 7, 28, 56, and 90 days, respectively.

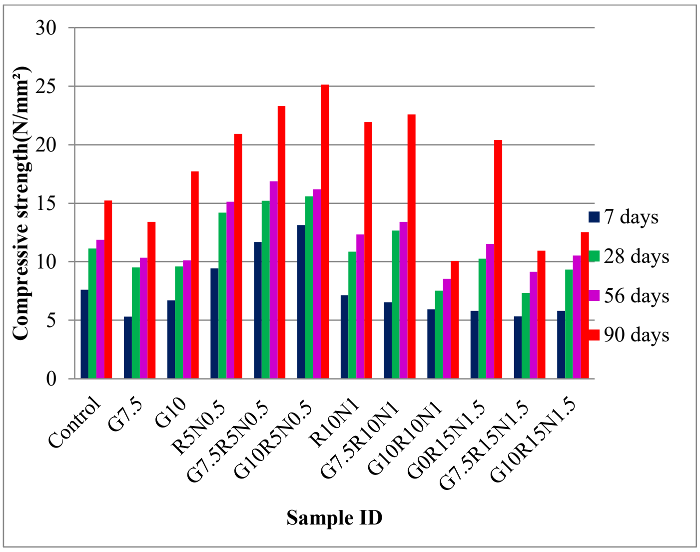

Figure 2. Compressive strength of engineered mortars at various maturity ages

3.5. Abrasion

The abrasion resistances of mortar mixes incorporating varying proportions of Nano silica and other SCMs are presented in Figure 3. The reference mix with 100% cement and zero additions (depicted with the ID G0R0N0) in the Fig recorded 20% resistance while the two mortar mixes with binary binders (i.e. cement plus a SCM) depicted as G7.5R0N0 and G10R0N0 gave higher resistance than the reference mortar. Mortar mixes with 0.5% NS gave resistance ranging from 38 to 100%, mortar mixes with 1% NS got resistance within the range 28 to 69 % and those incorporating 1.5 % NS recorded abrasion resistance ranging from 15-68 %.

Considering the mixes with 0% NS addition, it is noted that mortars with the binary binders recorded lower abrasion loss compare to the control mortar. This high resistance is related to filler effect commonly reported of SCMs. [21] and [22] reported similar observations. All the mixes with 0.5% NS are observed to possess higher abrasion resistance than the control mortar, all the mixes with lower or higher NS proportions. For instance, mixes G7.5R5N0.5 and G10R0.5N0.5 had 78 and 100 percent improvement respectively over the control mix in terms of abrasion resistance.

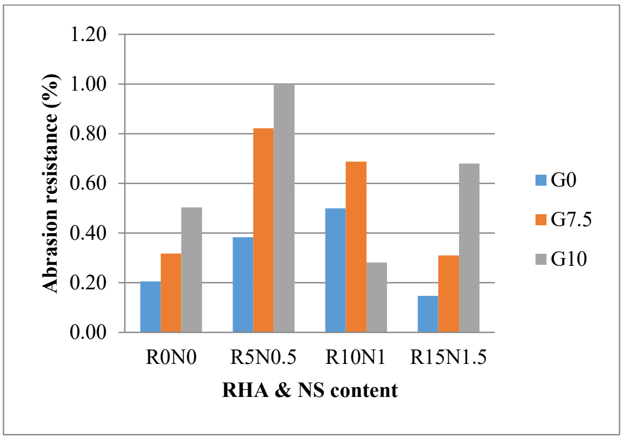

Figure 3 Abrasion resistance of engineered mortars

Considering the mixes with1% NS, the mixes G0R10N1, G7.5R10N1 and G10R10N1 recorded abrasion resistances that are37 %, 61% and 10% improvement over the control mix. These performances also indicate lower abrasion loss than the mixes with binary binders. The same trend is observed with the mortar mixes incorporating 1.5 %NS except for mix G0R10N1.5 which gave poorer resistance than the control mix. However, none of the mixes with either 1% or 1.5% NS got as high resistance as those incorporating 0.5 % NS. The reduction in the effectiveness of the mixes with higher NS content is attributable to the effect of agglomeration in which the mass particles might have clustered in an area. [23] and [24] both reported similar agglomeration effect on the microstructure of composites incorporating SCMs especially the silica nanoparticles. In all, 0.5% NS gave higher abrasion resistance than the control and all other mixes with higher NS content.

IV. CONCLUSIONS

This study sets out to appreciate the effect of Nano silica content on the strength and abrasion performance of cement mortars containing agro waste ashes. Experimental findings are reported, it is concluded that:

i. NS and RHA are highly reactive pozzolans while GSA is not a pozzolan
ii. NS addition enhanced both early and later age compressive strength
iii. Mixes with 0.5% NS gave higher abrasion resistance than the control and all other mixes with higher NS content.

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