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Use of Construction Waste with Nano-Silica Extracted from Rice Husk in Concrete Production

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Abstract

The use of construction and demolition waste (CDW) as recycled aggregates in concrete made from rice husk-based nano-silica is examined. In this research, rice husk ash (RHA) in nano-silica form was used as partial replacement for cement. Silica oxide was extracted and purified by dissolving RHA in sodium hydroxide solution at 100°C for four hours. The filtrate of the mixture was titrated with 10 % H_2SO_4 thereby producing silica oxide precipitate. This precipitate was characterized and found to contain 95.5 % SiO_2 and 4.5 % of other impurities. The silica oxide precipitate was grinded to nano particle size and characterized. Experimental results show that: 4% of cement content can be replaced with RHA nano-silica and can be used together with 25 % natural aggregate being replaced with construction waste to produce concrete of equivalent compressive strength to that of 100 % natural aggregate. While the compressive strength of concrete made with only recycled aggregate is very low compared with that of natural aggregate. It was recommended that 4 % nano-silica ash and 25 % recycled wastes be used as partial replacement of cement and natural aggregates respectively.

Keywords

Rice husk ash; Recycled wastes; Cement; Natural aggregates.

1.0 Introduction

Construction and Demolition Waste (CDW) is increasingly seen as a valuable source of recycle engineering material for the construction industry (Kuosa, 2012). Debris from collapsed and demolished structures can be recycled and reused as aggregates in concrete production. Construction wastes come from defected and damaged concrete structures or structural elements from site during construction. Such materials include broken blocks and demolished concrete. The disposal of these waste materials is one of the main problems in construction industry due to lack of sufficient space and cost of movement of these materials (Patil and Shingad, et. al., 2016). These materials can be recycled and re-used as partial or total replacement for the normal aggregate for concrete production in the construction industries. This will not only lead to massive decrease in the use of natural aggregates (NA) but also reduce the dumping of debris on the site. The utilization of recycled aggregates (RA) will be a good solution to the problem of loss due to excess / waste concrete materials and reduction of cost of carting away the demolished material provided that the desired quality of concrete is achieved (Fursule, et. al., 2017).

However, the large variations between the properties of the NA and RA such as: lower density, higher water absorption and porosity is a threat to the use of recycled aggregates in concrete (Mukharjee and Barai, 2015). The main cause of these problems related to these recycled aggregates is the attached mortar which differentiates them from natural aggregate (Mukharjee and Barai, 2015). It has also been found that there were reductions in compressive strength, elastic modulus, durability of RA compared to NA (Mukharjee and Barai, 2015). The properties of RA can be improved by addition of nano-silica products to build up the mechanical and chemical characteristics of the parent materials. Nano materials are materials with one of the dimensions less than 100^{-9} m (Patil and Shingade, 2016; Fursule, et. al.,. 2017).

Although, nano-silica can improve the properties of recycled aggregate, its availability and cost implication must also be put into consideration. Nano-silica can be produced from smelting quartz sand, however, sodium silicate produced by smelting quartz sand and carbonate at 1300^{o}C not only requires a large quantity of energy, but also needs further purification (Ghorbani, et. al., 2015). Nano-silica produced in this method can generate noise and environmental pollution. The extraction of amorphous silica from biomass plants (organic) yields high quality, environmental friendly and cost effective product at lower temperature as opposed to high energy processing of inorganics (Ghorbani, et. al., 2015). It has been established that certain plants, including Equisetaceae, Graminae, Cyperaceae and Poaceae contain high levels of silica in the form of hydrated silica deposited in the tissue (Ghorbani, et. al., 2015). These plant species contain high levels of silica accumulated contents in the range of 5 to 20 % of their dry weights. Several studies were conducted in relation to silica distribution, precipitation, physiology and extraction from many plants such as rice husks, wheat husks, bamboo and sugar beet pulps (Ghorbani, et. al., 2015, Motomura, et. al., 2006). Among this, rice husk (RH) is mostly available in Nigeria, hence, in this study nano-silica extracted from rice husk was used.

Rice is an important crop in Nigeria, it is relatively easy to produce and it is grown for sale and for home consumption. Its availability has made it part of the everyday diet of many Nigerians. Rice production in Nigeria reached a peak of 3.7 million tonnes in 2017 (Bello et. al., 2017). Rice husks, the hard protecting coverings of rice grains, is needed to be removed before processing for food. This husk is a waste product but contains high content of silica (Ghorbani, et. al., 2015). Singh, et. al., (2008); Sharifnasab and Alamooti, (2017), reported that the constituents of rice husk are hydrated silicon and organic material consisting of cellulose. The annual generation of rice husk is estimated to be about one-fifth of the annual gross rice production throughout the world (Ghorbani, et. al., 2015). Although, many farmers use it as feed in their poultry, the disposal of remaining waste still constitutes great environmental pollution in Nigeria. It has limited applicability in stock-breeding, because it contains more than 70 % of lignin-cellulose material and more than 20 % of amorphous SiO_2 (Ghorbani, et. al., 2015, Sharifnasab and Alamooti, 2017). RH is a good source of silica, when burnt; it yields 14–20 % ash, which contains 80–95 % silica in the crystalline form together with some amounts of metallic impurities (Ghorbani, et. al., 2015). Patil, et.al., (2018) found the percentage to be 89.28±0.03 %. Ghobani et.al., (2015) reported that RHA leached with acid had 85.5 % silica content. However, some impurities were found in it. These impurities include SO_3 at 1.4 %, K_2O at 0.99 %, CaO at 5.7 %, Fe_2O_3 at 0.55 %, CuO at 0.021 %, ZnO at 0.053 %, PbO at 0.009 %, Na_2O at 0.99 %, TiO_2 at 0.075 % and MgO at 0.03 %. Sharifnasab and Alamooti, (2017) found almost all the impurities in similar contents. Geetha and Ananthiand, (2016) also reported that such impurities are present in RHA similar to results of Ghosh, (2013). However, when pretreated and burnt under controlled conditions, amorphous silica of high purity and ultrafine particle size are produced (Sharifnasab and Alamooti, 2017).

2.0 Methodology

2.1 Materials

The materials used are: rice husk, sulphuric acid (H_2SO_4), sodium hydroxide (NaOH), construction wastes, cement, granite, sand and water.

2.2 Silica extraction from rice husk

Rice husk waste was collected from Fowowe Rice Mill at Odo-Atan, Erin-Oke, Osun State. The sample was washed in water to remove stone and solid particles. It was thereafter sun dried for 48 hours, and then blown in open air to remove the debris from it. The clean sample was pretreated with water containing 5 % H_2SO_4. It was then washed thoroughly in distilled water and dried again in open day sun for another forty eight hours. The rice husk was burnt at constant temperature of 800°C for five hours to produce carbonized rice husk ash. The carbonized rice husk was further burnt at 800°C for another five hours to become rice husk ash (RHA). The RHA was then dispensed in 500 mL of 0.5 M NaOH aqueous solution and heated at 100°C for four hours under vigorous stirring to dissolve silica and produce sodium silicate. The solution obtained was filtered to remove the non-reactive impurities. The filtrated sodium silicate solution was allowed to cool to room temperature and titrated with 10 % H_2SO_4 to pH 7 under vigorous stirring.

The solution was stirred for twenty four hours and cooled for forty eight hours at room temperature to allow the silica gel to slowly precipitate. A fragment was formed which was filtered and washed with water for several times to remove the sulphate salt. It was then filtered. The clean silica gel was freeze-dried for twelve hours. The frozen solid silica was ground with mortal. It was later re-grinded with electric grinding machine. The silica particles then passed through 30 µm sieve vibrated with the aid of mechanical shakers. Hence, silica powder was formed.

Chemical analysis was carried out on this powder with the aid of scanning electron microscope (SEM) and XRD measurements were carried out at Geological Centre, Kaduna. The silica powder was stored for further experiment.

2.3 Preparation of nano-silica from rice husk powder

Measured silica powder was put inside a beaker and dissolved in water. The mixture was then stirred uniformly to ensure uniform dispersion of nano-silica particles. The mixture was further grinded with electric milling machine to further reduce the size and the mixture still in liquid form passed through 50 nano meter sieve, hence it became rice husk ash nano-silica (RHANSi). The RHANSi for 2 % replacement of cement was stored in plastic containers. These procedures were repeated for: 3 % and 4 % replacement of cement.

2.4 Control mix with natural aggregate

Control mix of C20/25 Mix was designed using COREN concrete design manual (COREN 2017) and (BSI, 2006). It is a mixture of cement, natural aggregates (sand and granite) and water (no RHANSi). The coarse and fine aggregate were washed to remove all dirt. The concrete was mixed in pan mixer using constant water to binder ratio of 2:5. Clean natural water was used for the casting. The slump test was done immediately after mixing. Concrete test specimens of 150 x 150 x 150 mm cubes were casted. The cubes that were casted were kept in a curing tank. Compressive strength test was done after curing for fourteen days and twenty eight days. Three cube specimens were crushed as a set. The average compressive strength was determined per set.

2.5 Casting concrete with construction wastes

Construction wastes were taken from construction site of the Redeemed Christian Church of God and Dominion Sanctuary at Gwagwalada in Abuja. The concrete was cast with construction waste as replacement for NA using (COREN 2017) and (British Standards Institution, 2006). 25 % NA were replaced with RA. The same procedure was also repeated for 50 % replacement of NA with RA. The concrete cubes were cured in water tank and crushed at fourteen and twenty eight days.

2.6 Casting concrete using demolition waste with rice husk ash nano-silica

Table 1 present the mix proportions by volume for 2 , 3 and 4% RHANSi replacements of cement at 25 and 50% replacement of natural aggregates with demolition/recycled aggregates. Natural aggregates (sand and granite) were measured then recycled waste of 25% and 50% of natural aggregates were added for 25 and 50 % replacements respectively. The aggregates (sand, granite and recycled waste), cement and nano-silica were mixed together in a concrete mixer for 5 minutes, the water added and mixed for another 5 minutes. The mixture was done in accordance with COREN Concrete Mix Design Manual (COREN, 2017) and BS EN 206 (BSI, 2006). Concrete was then poured in 150 x 150 x 150 mm cube molds. The concrete in the cube was compacted in three layers using 20 mm compacting rod. The cubes were removed after twenty four hours and placed inside curing tanks for fourteen and twenty eight days before subjected to compressive strength test. **Figure 1** below is the flow chart presenting the processes of producing rice husk ash nano-silica (RHANSi) from the raw rice husk (RH).

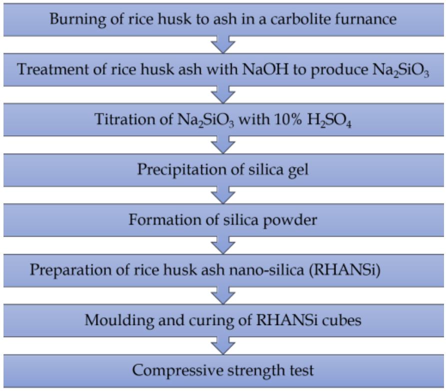

Figure 1: *Flow chart of production of RHANSi from RH*

Table 1a: Volumetric measurements for 1:2:4 concrete mix for 25 % replacement of natural aggregates with recycled wastes

% of Nano-silica	Volume (cm³)					No. of casted cubes
	Recycles Aggregate	Cement	Sand	Granite	Nano-silica	
2%	3750	2450	3750	7500	50	3
3%	3750	2425	3750	7500	75	3
4%	3750	2400	3750	7500	100	3

Table 1b: Volumetric measurements for 1:2:4 concrete mix for 50 % replacement of natural aggregates with recycled wastes

% of Nano-silica	Volume (cm³)					No. of casted cubes
	Recycles Aggregate	Cement	Sand	Granite	Nano-silica	
2%	7500	2450	2500	5000	50	3
3%	7500	2425	2500	5000	75	3
4%	7500	2400	2500	5000	100	3

3.0 Results and Discussion

3.1 Chemical properties/composition of RHA produced from RH

After burning the rice husk (RH), grey ash was formed called rice husk ash (RHA). The chemical composition of the RHA is presented in Table

2. It can be deduced that RHA contains 89.9 % SiO_2, hence an N- class pozzolana (ASM C 618- 91). This is similar to results of Ghosh, (2013) which found silica to be between 80-90 % composition in rice husk.

Table 2: Chemical Compositions of Rice Husk Ash

Compound	Composition (%)
SiO_2	89.90
SO_3	1.40
K_2O	0.99
CaO	5.70
Fe_2O_3	0.55
CuO	0.02
ZnO	0.05
PbO	0.01
Na_2O	0.99
TiO_2	0.07
MgO	0.03

3.2 Chemical composition of extracted nano-silica from rice husk ash

After dissolving RHA in a solution that contained 0.5 M of NaOH and heated for four hours, SiO_2 inside RHA reacted with NaOH to produce Na_2SiO_3. The chemical composition of this extracted silica is shown in **Table 3**.

$$NaOH + SiO_2 \rightarrow SiO_2 \qquad (1)$$

Table 3: Chemical composition of silica extracted from rice husk

Composition (%)	Nano-silica Extracted
SiO_2	95.500
SO_3	2.000
K2O	0.680
CaO	0.030
Cr_2O_3	0.018
Fe_2O_3	0.827
CuO	0.024
ZnO	0.002
PbO	0.015
Na_2O	0.500
TiO_2	0.404

From the results, SiO_2 composition had increased to 95.5 % which was before purification. This is similar to result of Sharifnasab and Alamooti, (2017) which found 94.5 % SiO_2 in RHA. Ghorbani, et. al., (2015) found it as high as 95.5 % SiO_2 after leaching with HCl. Ghosh, (2013) discovered between 95-98 % SiO_2 in RHA. This is also similar to results from Nayel, et. al., (2018) whose value was 97 %. However, some impurities were still found in it.

3.3 Compressive strength of 50 % replacement with recycled aggregate at 14 days

The graphical representative of the compressive strength of 50 % replacement with RA at 14 days is presented in Figure 2

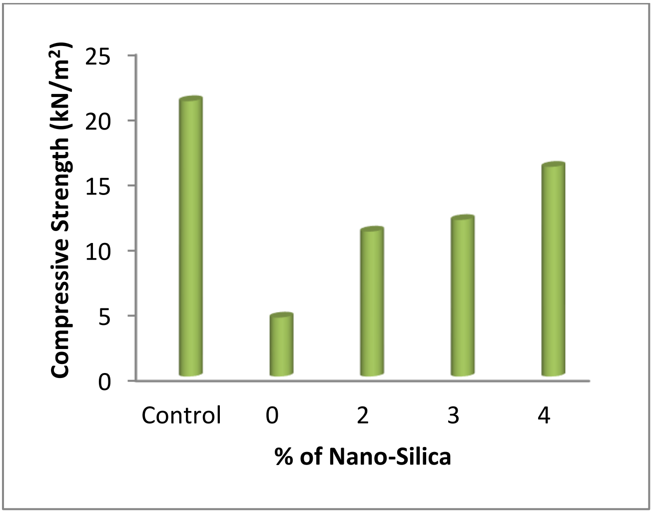

Figure 2. Compressive strength of 50 % replacement at 14 days

It can be observed that the compressive strength of the control mix is 21.111 kN/m^2. The compressive strength dropped to 4.952 kN/m^2 after replacing the NA with 50 % RA at 0 % RHANSi, but increased to 11.111 kN/m^2 after replacing cement with 2 % RHANSi. There was further increase in strength to 12.000 kN/m² after replacing cement with 3 % RHANSi. The replacement of cement with 4 % NSA improved the strength to 16.074 kN/m². This shows that RHANSi content between 2 – 4 % improved the compressive strength of concrete but still fall below the strength of the control mix (0% RHANSi) at 14 days.

3.4 Compressive strengths 50% replacement of recycle aggregate at 28 days

The 28-day compressive strength at 50 % replacement of NA with RA for: 0, 2, 3 and 4% replacement of cement with RHANSi in 1:2:4 concrete mixes is presented in **Figure 3.**

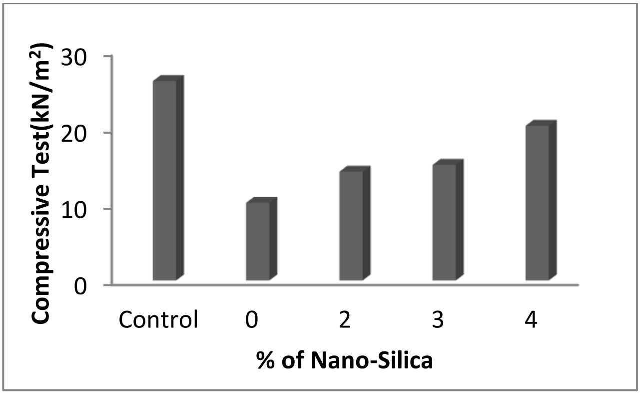

Figure 3. Compressive strength of 50 % replacement at 28 days

The strength at 28 days of 50 % replacement of NA with RA of 0 % RHANSi was 10.148 kN/m². This shows that nano-silica concrete gained strength with age as 4.951 kN/m² was recorded at 14 days. However, it is lower to the strength of the control mix which is 26.074 kN/m² at 28 days. Replacement of cement with 2 % RHANSi gave compressive strength of 14.222 kN/m². The replacement of cement with 3 % RHANSi improved the strength to 15.111 kN/m². The replacement with 4 % RHANSi improved the strength to 20.222 kN/m². This shows that nano-silica from rice husk is a potentially good pozzolana in concrete.

3.5 Compressive strengths of 25 % replacement of recycle aggregate at 14 days

The result of compressive strength at 25% replacement with RA for 0, 2, 3 and 4 % replacement of cement with RHANSi is presented in **Figure 4**. The replacement of NA with 50 % RA resulted in concrete dropping in strength to 4.519 kN/m^2 for 0 % RHANSi but this is lower than the strength at 25% replacement (Figure 3 and 4). This shows that the lesser the volume of RA in concrete, the stronger the concrete. The replacement of cement with 2 % RHANSi increased the strength to 19.778 kN/m^2, which is below that of the control. Replacing cement with 3 % RHANSi gave strength of 21.482 kN/m^2, which is above the control strength of 21.111 kN/m^2. The 4% replacement of cement gave the strength of 22.222 kN/m^2. This shows that replacing cement content with 3-4 % RHANSi can improve the strength of concrete of 25 % RA at 14 days.

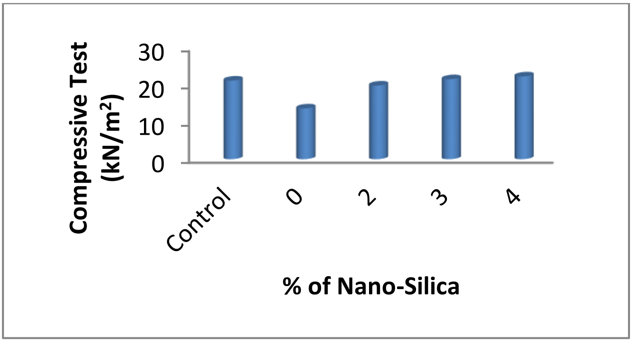

Figure 4. Compressive strength of 25 % replacement at 14 days

3.6 Compressive strength and slump of 25% replacement with recycled aggregate at 28 days

Figure 5 is a pictorial comparison of the compressive strength of concrete for 0, 2, 3 and 4% RHANSi with 25 % recycled aggregates at 28 days.

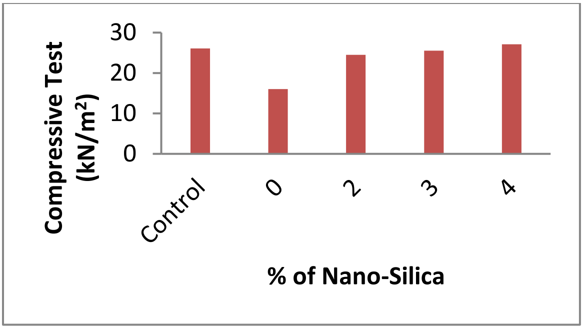

Figure 5. Compressive Strength of 25 % replacement at 28 days

The strength of replacement of NA with 25 % RA and 0 % NSA gave the compressive strength of 16.044kN/m^2 at 28days (**Figure 5**), this is a gain in strength over 14 day's strength. The replacement of cement with 2 % RHANSi improved the concrete strength to 24.518 kN/m^2 at 28 days. The replacement of cement content with 3 % RHANSi further improved the concrete strength to 25.556 kN/m^2 (see **Figure 5**), but this is less than the strength of the control mix (26.074kN/m^2). This shows that 3 % RHANSi replacement of cement content may not be best option since the compressive strength is lesser than that of the control mix. However, at 4 % replacement, the compressive strength of 27.111 kN/m^2 was recorded. This is greater than control mix strength. It can be said that replacing cement content with 4 % RHANSi at 25 % replacement of NA with recycled aggregate is an appropriate mix.

4.0 Conclusion

This research has shown how to produce nano-silica in an economical way within laboratory conditions. Nano-silica extracted from rice husk can partially replace cement in concrete made from recycled construction waste and could be used on structural members that are not subjected to high compressive strength.

The research has revealed the following:

i. RHA contains 89% silica oxide, which is an indication of a good binder, N- class pozzolans.
ii. Concrete cast with ordinary 50 % replacement of NA with RA has low compressive strength compared with 25 % and 0 % replacements.

iii. Nano-silica can be produced from rice husk after burning at 1000 ^oC.
iv. The strength of concrete improves with increase in RHANSi contents
v. Partial replacement of cement with RHANSi at 2 %, 3 % and 4 % improved concrete strength at 14 and 28 days.
vi. -The compressive strength of concrete cast with 25 % replacement of NA with RA is better than that of 50 % partial replacement. The compressive strengths decrease with increase in the content of recycled aggregates for 0 % NSA concrete.
vii. The replacement of 4 % cement content with NSA gave a higher compressive strength than the concrete cast with ordinary NA.

It is recommended that other researchers should carryout split and flexural strength tests on concrete cast with partial replacement of natural aggregate with recycled aggregate and partial replacement of cement with rice husk nano-silica. In addition, there is need for further research into change in compressive strength at 7, 21, 56 and 90 days. The need to generate nano-silica from other sources and used in conjunction with recycled aggregates in concrete is also recommended.

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