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Mechanical Properties of Rice Husk Ash (RHA) Nano-Silica Concrete

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A B S T R A C T

In this research, the effect of Rice husk ash (RHA) Nano-silica on mechanical properties of concrete was investigated. Portland Limestone Cement (PLC) was used in this research work and Nano-silica was produced from RHA using the acid treatment process. The Nano-silica obtained from RHA was tested for Oxide composition, percentage purity using x-ray fluorescence (XRF)). About seventy-two (72) concrete cubes of size 100mm x 100mm x 100mm were produced with varying percentage of RHA nano silica from 3 – 15% in 3% step increment. The concrete cubes produced were cured inside water for 3, 7, 14, and 28 days. Compressive and splitting tensile strength test were conducted for each curing day. The results have shown that the Nano-silica produced were silicon oxide particles and had 94.5% purity. The Nano silica-concrete has a good workability based on BS EN 206-1 (2000) standard. The compressive strength of concrete increased as the content of RHA Nano-silica increased in the concrete matrix. As such, 9% RHA Nano-silica in the concrete gave the highest compressive strength of 39.71N/mm2 at 28days, while the 0% RHA Nano-silica had the compressive strength of 36.12N/mm2. At the 56 days, mix 2 (6% RHA Nano-silicas) had the highest strength of 41.21N/mm2 while the 0% RHA Nano-silica had a compressive strength of 37.26N/mm2. It was observed that an increase in the quantity of Nano-silica in the concrete paste resulted in a corresponding increase in water content required for achieving standard consistency. The test result shows that the presence of Nano-silica can considerably improve the resistance of water penetration in the concrete. At 28 days curing, water absorption values decreased considerably with an increase in Nano-silica content up to 9%.

Keywords: Nano-silica, Concrete, Rice Husk Ash, compressive strength,

1. Introduction

Cement is the binding material for concrete, and its production is resource and energy intensive, and emits large amounts of greenhouse gas (CO_2) into the atmosphere. An estimated 34 million metric tons of Portland cement concrete are produced each year, accounting for approximately 5-8% of all anthropogenic CO_2 emissions (Olivier et al, 2016). According to Siddique and Khan (2011), the cement industry accounts for approximately 7% of global CO_2 emissions, which contribute to global warming.

The average rise in Earth's temperature over the next 100 years is estimated to be between 1.9 and 5.3ºC (Pacheco *et al,* 2013). Methods of reducing the amount of this gas released into the atmosphere are constantly being investigated, and the use of supplementary Cementitious materials in concrete has proven to be a step in the right direction. As such, the construction industry need to reduce the amount of cement used in concrete, the consumption of energy during cement production, and consequently a reduction in the release of carbon dioxide, the emphasis on the use of blended types of cement has increased.

In the modern age of concrete construction, researchers are taking advantage of the supplementary cementitious materials that give concrete greater strength and durability (Daghash, 2013). Joy (2005) defines supplementary cementitious materials as a solid materials which are finely grounded and is used to replace some proportion of the cement in a concrete mix. When these SCMs are added to the mixture of water and cement, they react chemically with the hydrating cement to form a modified paste microstructure thereby improving the mixture's workability, mechanical properties and durability. One of the technologies from the research with supplementary cementitious materials that is now into the concrete design arena is the use of pozzolanic Nano-particles in the concrete matrix. Using pozzolanic nano-particles in a cement/concrete mixture, the development of the strength-bearing crystals of cement paste can be increased. An example of the nano-particles is Nano-silica, which will be extensively used in this research.

Nano-scaled silica particles (Nano-silica) have a filler effect by filling up the voids between the cement grains and reacting chemically to form Ca(OH)2 (Zapata et al, 2013). With the right composition and effective mix of cement/concrete, water and Nano-silica, it results to higher packing density and also contributes to strength enhancement due to the reduced capillary porosity. Zapata et al (2013) stated that Nano-silica has a pozzolanic reactivity that is important in developing high performance concrete. Nano-silica formed from rice husk has the potential to enhance the mechanical behavior of the concrete composites and reducing the overall construction cost.

Rice husk is a by-product of rice milling that is annually produced in tons (Fapohunda et al., 2017). It is an agricultural waste and its disposal presents a major challenge in the management of the enviroNano-silicaent. Rice husk accounts for approximately 20-23% globally of total paddy rice weight (IRRI, 2008) and large quantities of rice husk are produced annually around the milling centres in Nigeria. The enormous heaps of these rice husks which have piled up since the 1960 are now posing various problems to the enviroNano-silicaent. The quantity of rice milling by-products generated in Nigeria annually was estimated at about 1,032,993.6 metric tons (NAERLS, 2004).

The disposal is usually done by burning to minimize its high volumes (Al-Awan et al, 2022). The indiscriminate burning of the rice husk is associated with many enviroNano-silicaental problems (Amin and Abdelsalam, 2019). The rice husk ash (RHA) produced by burning the husk is also considered a severe pollutant to the enviroNano-silicaent (Al-Awan et al, 2022). It is therefore necessary to find a solution to minimize its release to the enviroNano-silicaent. SCMs currently serve as one of the primary tools for reducing carbon dioxide emissions associated with concrete production. The demand for SCMs to reduce CO2 emissions from concrete production is increasing (Maria et al, 2019).

1.1 Materials and Method

1.1.1 Materials

The materials used in this research are cement, coarse aggregates, fine aggregate, Rice Husk, Hydrochloric acid (HCl), and water.

Water cement ratio: Water Cement ratio used is 0.5

Ordinary Portland Cement (OPC) was used for this research work.

Nano-silicas: Nano-silicas were produced from RHA using the acid treatment process.

Aggregates: Fine and coarse aggregate was used. Coarse aggregate that passed through 12 mm sieve but retaining on 4mm sieve was used. Well graded fine aggregate that passed through 2.36mm sieve were used.

1.1.2 Method

The materials used for the research were subjected to test according to the respective standards.

1.Specific gravity of cement

The specific gravity of cement was determined in accordance with BS EN 196-2(2016).

2. Specific gravity test.

The specific gravity test for fine aggregate was performed according to BS EN 1097-2 (2010).

3. Particle size distribution (Sieve Analysis)

The particle size distribution test was performed according to BS EN 983-1(2012).

4. Coarse Aggregate

The aggregates were made of size passing sieve 25.2 and retaining on sieve size 4.75mm. The following tests were performed to determine the suitability of the material for concrete:

i) Aggregate crushing value,

ii) Impact resistance and

iii) specific gravity

Aggregate Crushing Value (ACV)

The Aggregate Crushing Value (ACV) Test was performed according to BS EN 1097-2 (2010)

Impact Value Test

The Impact value test was performed according to BS EN 1097-2 (2010).

Specific Gravity test

The Specific Gravity test was performed according to BS EN 1097-2(2010)

4. **Nano-silica from Rice Husk**

To produce Nano-silica particles, the following steps are followed. The procedure was adopted from work by Dugguh et al, (2021):

a) Converting Rice Husk to Rice Husk Ash (RHA)

b) Nano-silica particles from Rice Husk Ash (RHA)

5. Mix Design

Absolute volume was used for the mix with ratio 1:2:3 for grade 30 concrete. The Nano-silica concrete is mixed in similar way. Mix 0 is the control mix which is one part whole cement to two parts sand to three parts coarse aggregate. Mix 1 means one percentage (3%) of the binder is of Nano-silica and ninety-nine percent (99%) as cement forming one (1) part of binder, two (2) part of sand and 3 part of coarse aggregate. For example, if 100g of cement is used as binder, then 1g is Nano-silica and 99g of cement will form binder as one (1) part Thus, 1:2:3, ((99+1):2:3) will be mix 0 and mix 1 respectively.

Table 1: Concrete Mix used

Replacement by weight of cement	**Abbreviation**		**Material Proportion**	
			Cement(kg)	Nano silica(g)
% Nano silica Replacement	CTR - Control	Mix 0	10	0
3% Nano-silica replacement	N3	Mix 1	9.95	50
6% Nano-silica replacement	N6	Mix 2	9.9	100
9% Nano-silica replacement	N9	Mix 3	9.85	150
12% Nano-silica replacement	N12	Mix 4	9.8	200
15% Nano-silica replacement	N15	Mix 5	9.75	250

Thus table 1 indicates the replacement of Nano- silica by weight. Therefore, 108 cubes of size 100mm x 100mm were produced for the experiment.

Water Absorption Test of Nano-Silica concrete

The test was performed to evaluate absorption of water by the concrete concrete cubes according to BS EN 1881-122 (2011). Concrete cubes of size 100mm x100mm were produced and cured for 28days inside water, it was removed and oven dried at 105ºC for 24hours.The cubes oven dried were weighed,W_0 and immersed in water for 24hours and weighed, W_1. The difference in the weights of over the dry weight in percentage is the water absorption..

Workability (Slump)

The workability test was performed in accordance with BS EN 206-1(2000)

Compressive Strength of concrete cubes

The compressive strength test was performed as per BS EN 12350-2(2009). About seventy two (72) concrete cubes of size 100mm x 100mm x 100mm were produced with varying percentage of RHA Nano-silica from 3 – 15% in 3% step increment. The concrete cubes were cured in water for 3, 7, 14, and 28days, 3 concrete cubes were tested to obtain their compressive strength for each curing day.

Splitting tensile Strength test

The test was conducted as per ASTM C496 (2011). 18 cylindrical specimens 150mm x 300 mm were produced. They were tested at 28days. The failure load was recorded and the splitingt tensile strength was calculated.

3.0 Results

3.1Aggregate

Table 2 presents the % silt content, specific gravity, impact value and crushing value of both fine and course aggregates.

4.3.1 Fine Aggregate

Silt Content of fine aggregate

The silt content was found based on BS EN 1097-2 (2010) and the result is computed as shown in table 2. The silt content is 3.98%

Table 2: Test values for fine and coarse aggregate

	Silt content (%)	Specific gravity	Impact value (%)	Crushing Value (%)
Fine aggregate	3.98	2.63	-	-
Coarse aggregate	-	2.78	17.2	18.06
Code specification	8	2.4-3.0	<30	<30

Specific Gravity of fine aggregate

The specific gravity for fine aggregates is presented in Table 2, and the value is 2.63. It, was found to be within the limit specified by the standard. The specific gravity value indicated that the materials are of good quality. Lower values of specific gravity are indicated that the materials are weak porous.

Coarse Aggregates

Aggregate Crushing Value for Coarse

The ACV was performed according to BS EN 1097-2 (2010) and the result shows that the ACV is 18.06 % which falls within the allowable limit as stated by the standard. The crushing value of 18.06 for the coarse aggregate is also in conformity with the value of less than 30 (Table 2) specified by the standard. Therefore, the aggregates will resist crushing under compressive loading.

Aggregate Impact Value (AIV) Test for Coarse

The impact value test was performed according to BS EN 1097-2 (2010) and the value obtained was 17.2% , which is within the acceptable limit of less than 30 specified by the standard in Table 2.

Specific Gravity for Coarse aggregates

The specific gravity test was perfprmed according to BS EN 1097-2 (2010) and the result shows that the value of specific gravity of 2.78 falls within the standard specification as shown in Table 2.The specific gravity for both fine and coarse aggregates presented in the Table 2 are 2.63 and 2.78 respectively. These when compared to BS EN 1097-2 (2010) standard, were found to be within the limit specified. The specific gravity values obtained indicated that the materials are of good quality. Lower values of specific gravity indicated that the materials are weak and porous. The impact value is was found to be within the acceptable limit of less than 30 specified by the standard.

Therefore, based on the result, both fine and coarse aggregates are good and can be used for making concrete.

X-Ray Fluorescence (XRF) Analysis

XRF analysis was performed to establish the chemical composition of the sample as shown in table 3. The phenomenon is widely used for elemental analysis and chemical analysis, particularly in the investigation of building materials.

Table 3 XRF analysis for various samples

Elemental oxide	**Raw RHA (wt %)**	**Treated RHA (pure silica) (wt %)**	**Nano-silica (wt %)**
Na_2O	0.056	0.454	0.000
MgO	2.721	0.629	0.593
Al_2O_3	2.363	1.012	1.068
SiO_2	80.722	92.32	94.259
P_2O_5	8.109	1.808	1.792
SO_3	0.675	0.408	0.278
Cl	0.023	1.456	0.012
K_2O	2.341	0.733	0.776
CaO	1.394	0.256	0.278
TiO_2	0.203	0.113	0.096
Cr_2O_3	0.002	0.002	0.002
Mn_2O_3	0.233	0.079	0.079

Fe_2O_3	1.103	0.721	0.759
ZnO	0.046	0.008	0.002
SrO	0.009	0.002	0.000

This was done to estimate the percentage of silica oxide in the sample after it has being calcinated to a temperature of 700ºC. The XRF analysis was performed at the Multi-User Laboratory, Chemistry Department, Ahmadu Bello University, Zaria. Table 3 shows the XRF analysis of the raw RHA, Acid treated RHA and Nano-silica. It can be observed that, for example, sodium oxide (Na_2O) which was initially 0.056% became 0.00% when the Nano-silica was obtained as a result of the increase in the composition of SiO_2. Similarly, magnesium oxide (MgO) which was 2.721% became 1.068%, phosphorus pentoxide (P_2O_5) which was 8.109% became 1.792%, potassium oxide (K_2O) which was 2.341% became 0.776%, calcium oxide (CaO) which was 1.394% became 0.278% and so on. The silicon oxide (Si_2O) which has the highest percentage increased from 80.722% to about 94% making it the major compound. This might be due to increase in the amount of Nano silicate which contains amorphous silicon oxide (SiO2), or silica (Antiohos*et al*., 2013; Prasittisopin and Trejo, 2015) i.e Nano silica from rice husk is mainly silicon oxide. Therefore, the particle size of Nano-silica obtained from RHA is between 0-20 Nano-silica. The RHA contains a higher ratio of SiO2 approximately five times than that of cement (Amin and Abdelsalam, 2019).

4.8 Workability of Nano-Silica-concrete

The test was carried out as per BS EN 206-1 (2000) and the result is shown in Figure 1. According to BS EN 206-1, all the slump values are classified as S3 which means all the mixes were highly workable. Slump of class S3 are of high workability ranging 100 – 150 mm. Therefore, Nano-Silica-concrete has a good workability in all the mixes.

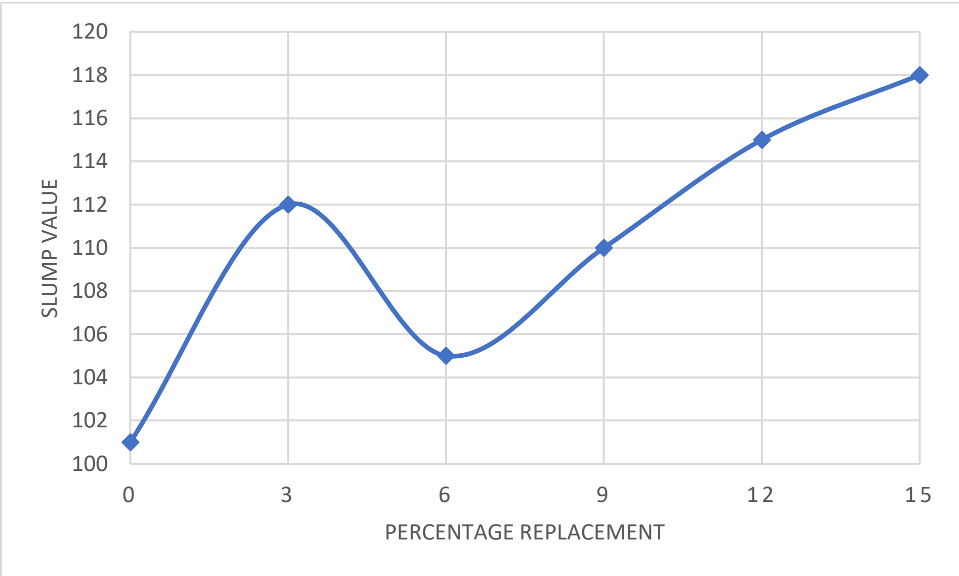

Figure 1: Slump test result.

4.9 Nano-silica concrete water absorption test

The tests result shows that the addition of Nano-silicate (NS) can considerably improve the resistance to water penetration through the concrete. A significant reduction in water absorption was observed after replacement of cement with RHA Nano-silica as shown in figure 2 .

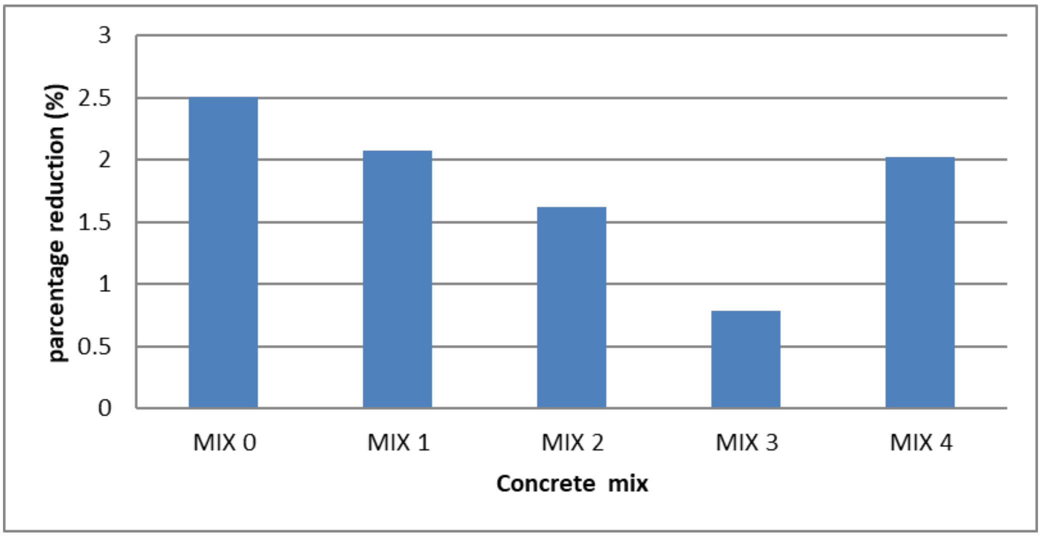

Figure 2: Nano-silica concrete water absorption

At 28 days curing, water absorption values decreased considerably with an increase in Nano-silica content up to 9%. At 3% Nano-silica, the value was lower compared to that of 0% Nano-silica. As the Nano-silica was used to replace cemen,t the water absorption in the mixes was decreased by more than two times compared to the 0% Nano-silica mix. The increase in resistance to water penetration can be accomplished by two phenomena. Nano-silica particles generate a large number of nucleation sites for hydration products and induce a homogeneous distribution of C-S-H gel and hence lesser pore structure as explained by Lawan *et al (*2021).

4.10 Compressive Strength Test

For strength development in Nano-silica concrete, 108 concrete cubes with varying percentage of RHA Nano-silica were produced. The concrete cubes are of 100mm in size. The cubes were cured and crushed at 3, 7, 14, 28, and 56 days to obtain the crushing value which was used to obtain the compressive strength. Figure 3 shows the graphical representation of the compressive strength against curing age of the cubes.

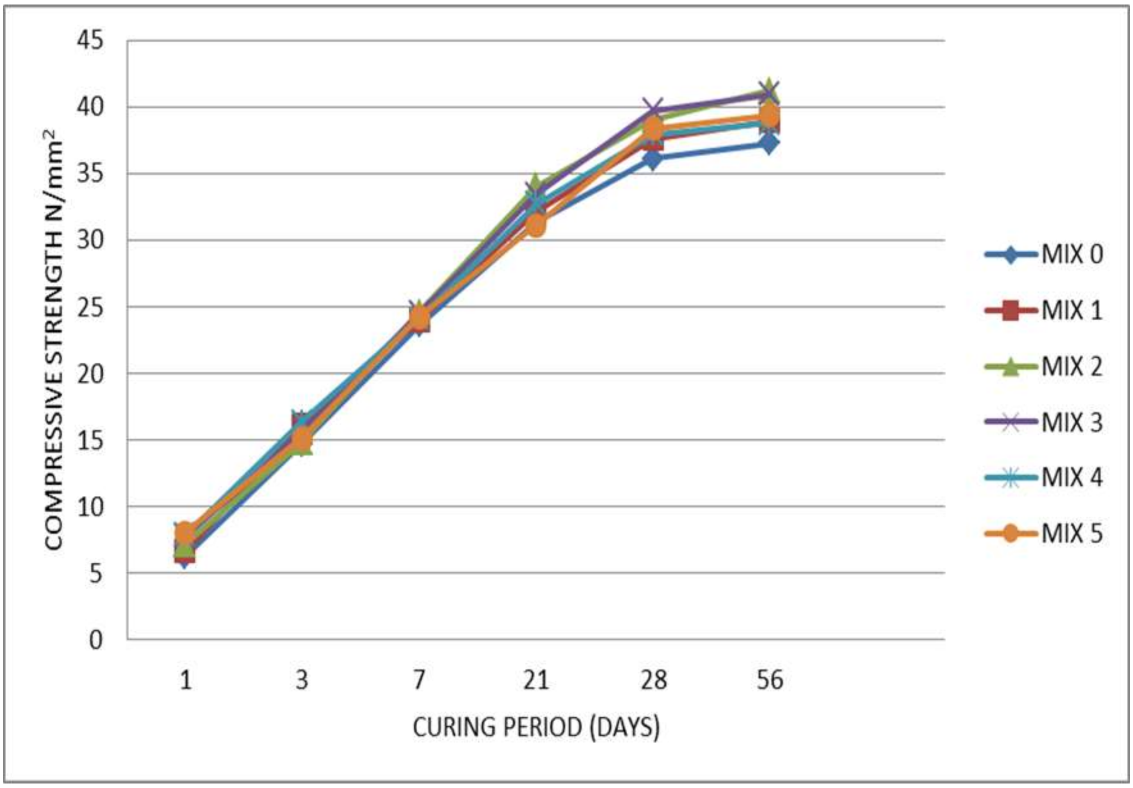

Figure 3: Compressive Strength of various RHA nano silica replacements against curing age

From figure 3, it can be seen that, at 28days, mix 0 (0% RHA Nano-silica) and mix 3 (9% RHA Nano-silica) had the highest and lowest compressive strength respectively. The compressive strength at 28days was observed to be 36.12N/mm^2 for mix 0 (control mix) and that of mix 3 is 39.71 N/mm^2 respectively. This is 2.12% more than the compressive strength of the 0% Nano-silica sample. The compressive strengths for mix 1, mix 2, mix 4 and mix 5 were obtained to be 37.6N/mm^2, 38.98N/mm^2, 37.93N/mm^2 and 38.36N/mm^2 respectively. All the samples have compressive strength which is more than the 0% Nano-silica at 28days.

Tthere is an early strength development with an increase in the Nano-silica from 3 to 15% within the first 24hours. This shows that, with 9-15% Nano-silica replacement, a significant early strength of concrete can be obtained as compared to the OPC concrete which had a compressive strength of 6.23N/mm^2. After 24hours, mix 5 had the highest compressive strength of 8.01N/mm2. The result shows that, the amount of RHA Nano-silica present causes rapid hydration and production of C_3S which is responsible for early strength development of concrete. This is due to the rapid production of C_3S which is produced from the reaction of NS with the hydration products of cement and water. From 7 – 21 days, the compressive strength gradually increases from mix 5 to mix 2. This could be as a result of the different rates of reactions and production of C_3S across the mixes due to the amount the RHA Nano-silica used to replace cement in the concrete mix. From the early strength development of the first 21days, mix 2 had the highest compressive strength of 34.05N/mm^2.

The maximum compressive strength at 56days recorded across the replacements is mix 0, mix1, mix 2, mix 3, mix 4 and mix 5 are 37.26N/mm^2, 38.96N/mm^2, 41.21N/mm^2, 40.93N/mm^2, 39.38N/mm^2 and 38.79N/mm^2 respectively, with mix 2 having the highest compressive strength. The drop in compressive strength from mix 5 to mix 2 could be attributed to the rapid hydration and agglomeration of unreacted RHA Nano-silica in the concrete mix. NS have a higher surface area and high surface energy as explained by Sanker et al (2016), which when added in the right quantity, leads to the effect filler effect and compact structure. They further explained that, as the amount of NS is increased in the mix, there is a corresponding increase in Nano-silicas agglomeration, surface area and nucleating effect of the materials producing C_3S and C_2S. The combination of NS with cement further increases the compressive strength of the concrete due to the filler effect and pozzolanic reaction, thereby filling the voids at nano scale and giving it a more refined and dense structure of the material as stated by Lawan et al 2021.Furthermore, the NS consumes the portlandite [Ca (OH)$_2$] to produce C-S-H and causes the hydrated product to be more homogenous. This creates a better bond between aggregates and cement paste, thereby improving over the mechanical performance of the concrete. The enhancement of the concrete can be attributed to the packing effect of the Nano-silica and the filler effect of the hydrated products to fill up the interstitial spaces inside the hardened microstructure of the concrete.

4.11 Splitting Tensile Strength Test

The splitting tensile strength is presented in Figure 4. From the figure, it can be seen that, the split tensile strength of the concrete samples increased with increase in NS content at 28 days.

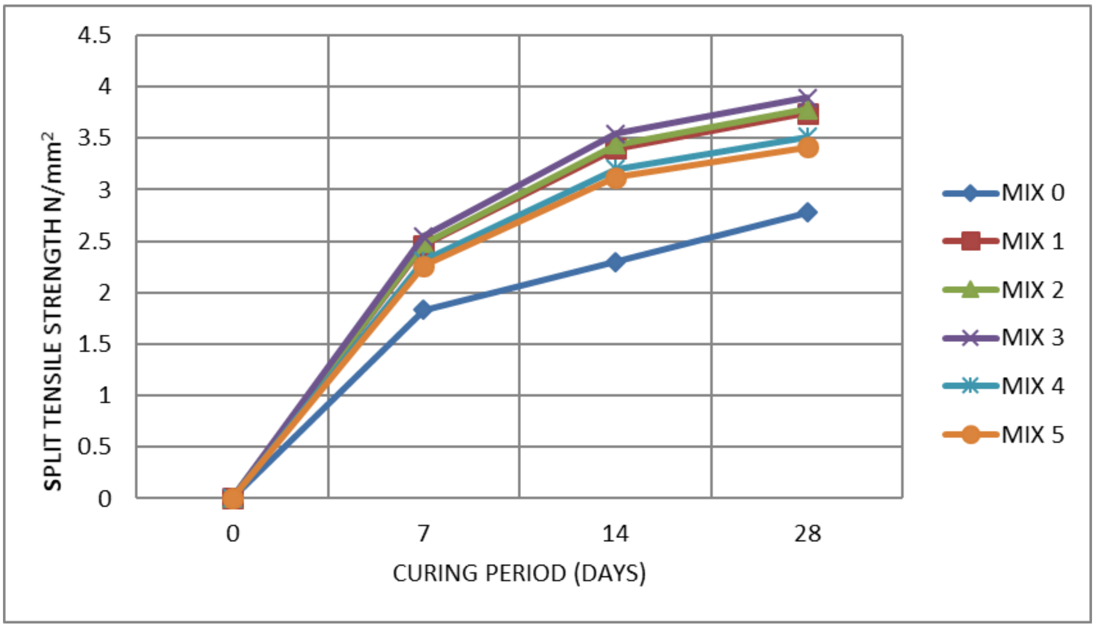

Figure 4: Split tensile strength of concrete samples with Nano-silica

Mix 3 had the maximum split tensile strength of 3.87N/mm^2 while the control sample (with no NS) had a splitting tensile strength of 2.78N/mm^2. Mix 1 (3% NS replacement), mix 2 (6% NS replacement), mix 4 (12%NS replacement) and mix 5 (15% NS replacement) had split tensile strength of 3.74N/mm^2, 3.78N/mm^2, 3.51N/mm^2 and 3.41N/mm^{2}respectively.All the samples containing NS showed significant tensile strength and were all more than the tensile strength observed for the control sample.

5. Conclusion

It can be concluded that the water content increases with an increase in the quantity of Nano-silica in the paste to achieve standard consistency, there's high workability in all the mixes with Nano-silica and reduction in setting time in Nano-silica concrete compared to the)% Nano-silical mix. Also the water absorption of sample with Nano-silica decreased compared to the 0% Nano-silica mix.

It can be concluded that concrete produced with RHA Nano-silica have high compressive and Tensile strength and are more resistant to Acid attack compared to the 0% Nano-silica sample.

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