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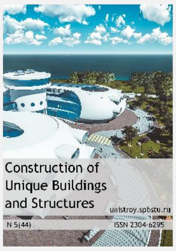

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Flexural strength of reinforced revibrated concrete beam with sawdust ash as a partial replacement for cement

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ABSTRACT

This article examines the flexural strength of reinforced and re-vibrated concrete beams using Saw Dust Ash (SDA) as a partial replacement for Ordinary Portland Cement (OPC). Chemical analysis of the SDA sample contains the major chemical oxides found in cement: SiO_2 (27.23%), Al_2O_3 (29.05), Fe_2O_3 (9.32%). Seven beams of sizes 150mm x 150mm x 600mm reinforced with 12mm diameter steel bars (Y12) were cast for each 0%, 5%, 10%, 15% and 20% replacements of OPC with SDA. The beams were re-vibrated for 20 seconds at an interval of 10 minutes successions up to 1 hour after initial vibration. Another set of three beams of same size and reinforcement for each percentage replacements of OPC with SDA were also cast but were not revibrated. Fifty beams were cast in total: thirty-five revibrated and fifteen non-revibrated beams and were all cured for 28 days. Flexural strength test carried out on each beam shows maximum flexural strength at 0% followed by 5% replacement at twenty (20) minutes revibration time lag interval. The maximum flexural strength attained were 10N/mm^2 at 0% then 9.5N/mm^2 at 5% for the revibrated beams respectively, while for non-revibrated beams 8.87N/mm^2 and 6.67N/mm^2 for 0% and 5% replacements were attained. Revibration is thus seen to improve the flexural strength of reinforced concrete beams and thus SDA can be used up to 5% to replace cement.

Contents

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1. Introduction

The cost of conventional building materials continue to increase as the majority of the population continues to fall below the poverty line. This has prompted the need to search for local materials as alternatives for the construction of functional, but low-cost buildings in both the rural and urban areas. Some of the local materials that have been used are earthen plaster [1], lateritic interlocking blocks and Palm kernel shell.

Continuous accumulation of wastes arising from industrial by-products and agricultural residue, create acute environmental problems both in terms of their treatment and in terms of disposal. The construction industry has been identified as the one that absorbs the majority of such materials as filler in concrete [2]. If these fillers have pozzolanic properties, they impart technical advantages to the resulting concrete and also enable larger quantities of cement replacement to be achieved [3]. Much less is known about re-vibration and its importance, the process in which a vibrator is reapplied to concrete at some time after initial vibration [4- 6].

Pozzolana are siliceous material, which by itself possesses no cementitious properties but in processed form and finely divided form, react in the presence of water with lime, to form compounds of low solubility having cementitious properties [7]. The use of industrial and agricultural by-product in cement production is an environmental friendly method of disposal of large quantities of materials that would otherwise pollute land, water and air thereby leading to social and environmental problems [8]. The presence of mineral admixtures from agricultural waste is also known to impart significant improvement in workability and durability of concrete. Although, technological and economic benefits are the main reasons for the use of mineral additions, it was observed that the prevention of environment contamination by means of proper waste disposal is an added advantage [9].

Saw dust Ash (SDA)

SDA is a waste material from the timber industry. It is produced as timber and sawn into planks at saw mills located in virtually all major towns in the country. This process is a daily activity causing heaps of saw dust to be generated after each day. The need to convert this waste product into a useful by-product is the focus of the study.

Some industrial wastes have been studied for use as supplementary cementing materials such as Fly ash [10 - 12], pulverized fuel ash [13], Volcanic ash [3], Rice husk ash and Corn cob ash [14,15].

An investigation was conducted on the usage of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar, assessment of the fresh concrete properties of self-compacting concrete containing SDA, and it was evident that ash from timber waste was a material capable of replacing cement [16 – 18]. Nigeria has thick forests with abundant tree from which saw dust is obtained during processing. Thus, there is an abundant raw material for the research. The current practice with SDA in abroad is as fuel for domestic cooking and for sand filling ditches in which case it constitutes environmental nuisance. Environmental pollution is controlled and job is created for our teaming unemployed youths who could become agents for supplying the SDA to concrete industries that needed it. In the long run, the use of SDA as partial replacement for cement is expected to bring about reduction in the cost of concrete production since cement is the most expensive constituent of concrete.

Flexural Strength of Reinforced Concrete Beams

Flexural strength of structural elements may be said to be its resistance to bending (flexural) and is determined either by the ultimate strength of the concrete yield stress f_{ck} or the steel reinforcement f_y. This resistance may then be divided by a proper factor of safety to determine what bending resistance is to be relied upon under working conditions. The bending is basically caused by load that acts transversely to its longitudinal axis. The flexural capacity is assessed in the bases of the plane section theory which describes the relationship between flexural capacity and geometric characteristics by considering the equilibrium conditions at critical cross section [19]. Prior to the existence of the ultimate strength theory in which the above is based, the elastic theory was used in the analysis of a beams resistance to bending.

Re-vibration and strength of agro-waste blended concrete

A research conducted suggests that re-vibration enhances the strength of concrete once done within the plastic stage of the concrete. Also it was clear that flexural strength of RHA concrete increases at the early stage of re-vibration, the flexural strength of RHA concrete decreases from 30 minutes to 60 minutes of re-vibration almost for all percentage replacement level of RHA. Further observations showed that revibration on early age retarded concrete in which the result shows that the maximum compressive strength was achieved when the concrete was revibrated and cured at older age, thus revibration improves many of the quality of hardened concrete [5, 6, 20].

Another investigation examined the effect of re-vibration on compressive strength of concrete and concluded that re-vibration resulted in enhancement of compressive strength when carried out within the initial setting time confirming that good re-vibration within standards increases compressive strength [5, 21, 22].

2. Aim

In this study the flexural strength of revibrated reinforced concrete beam is examined with saw dust ash (SDA) as partial replacement for cement. This is achieved through the following objectives:

- To determine the chemical and physical properties of SDA and preliminary tests on the constituent materials to be used;
- To cast, reinforce and re-vibrate 35 of the selected beams through 1hour at 10 minutes interval successions for each beam specimen, while 15 are non-revibrated giving a total of 50 beams of sizes 150mm x 150mm x 600mm;
- To experimentally determine the flexural strength of these beams after curing age of 28 days only.

3. Materials and Method

Materials

The materials used for the production of the beam specimens include: sand; crushed coarse aggregate with 20mm maximum size; water; cement; saw dust ash (SDA); high yield steel reinforcement of 12mm diameter as the main reinforcement and 8mm as the links (based on structural design). The above listed materials were carefully selected to meet the specifications for aggregates and constituents of concrete. This was achieved through the preliminary test like particle size distribution of sand and saw dust ash (SDA), chemical and physical analysis of SDA, specific gravity test, moisture content test and bulk density tests of sand and SDA. The cement, coarse and fine aggregates and water for which the test was carried out met requirements specified in standards [23] for sand, [24] for water, [25] for cement.

Saw dust ash (SDA): The SDA was obtained from Chanchaga timber shade in Minna. It was then dried and taken to Furnace at Shelter clay company Pago in Niger State, Nigeria. There it was burned at a control temperature of 800°C. Investigation of elemental composition of the ash was carried out in the laboratory using X-Ray Diffraction (XRD) machine to ascertain the quantum of oxides present. The result is presented in Table 2 and Fig.3.

Equipment: The apparatus used for these tests are a weighing machine; British standard sieves; concrete mixed; 150mm x 150mm x 600mm beam moulds; head pan; hand trowels; tamping rod; buckets; Poker vibrator and Universal Testing Machine for the flexural test results of the beams specimen after curing.

Method and preparation of beam specimen

The concrete work was carried out by batching using specific volume method of mix design for the constituent elements of concrete mix ratio of 1:2:4 was adopted throughout the design for every replacement of OPC and SDA with a constant water cement ratio of 0.5.

Fifty rectangular concrete beams specimens of sizes 150mm x 150mm x 600mm were cast for this study. Main reinforcement used was 12mm tensile steel bar (Y12) and a concrete cover of 25mm for all the beams specimens. The size of the links provided was 8mm steel bar each at regular spacing of 125mm c/c. The beam specimens were grouped into re-vibrated (35 beams) and non-revibrated (15 beams) out of the total numbers of 50 beams cast for this study. The material constituent of this concrete beams are cement, fine aggregate and coarse aggregate and SDA were used at different percentages of replacement. Main reinforcement used was 12mm tensile steel (Y12) and a concrete cover of 25mm for all the beams specimens were achieved. The size of the links provided was 8mm bar each at regular spacing of 125mm c/c. The beam specimens were categorized into re-vibrated (35 beams) and non-revibrated (15 beams) out of the total 50 numbers of beams cast.

The revibrated 35 beams were cast at 0, 5, 10, 15 and 20 % percentage replacement of OPC with SDA. For each of these replacement levels, seven beams were cast and re-vibrated 20sec at intervals of 10minutes successions through 1 hour for each level replacement. While for the non-revibrated 15 beams, three samples were cast each at percentage replacement corresponding to 0, 5, 10, 15 and 20 % respectively. Poker vibrator was used to initiate the compaction, vibration and re-vibration of the concrete mix in the mould for the beams specimen. The beams were de-moulded after 24 hours, cured for 28 days and afterwards tested for flexure (figure 5) according to specifications [26,27]. Results obtained are presented on tables 5, 6 and 7.

4. Results and Discussion

The results of chemical composition, preliminary test results on the constituent materials and the concrete are presented in tables 1, 2, 3, 4, 5, 6 and 7 respectively.

Aggregate characterization

The aggregates were tested for physical properties according to specifications such as: specific gravity, particle distribution test and bulk density were conducted according to standard [23].

Particle size analysis for fine, **coarse aggregates and SDA**: The results of particle size analysis of SDA, fine and coarse aggregates used in the study are presented in table 1 and figures 1 and 2 respectively.

Table 1. Particle size analysis of SDA

Sieve size(mm)	Weight Retained (g)	Percentage of Retained (%)	Cumulative Percentage Retained (%)	Cumulative Percentage Passing (%)
425µm	0.00	0.00	0.00	100.0
300µm	20.0	10.0	10.0	90.0
150µm	97.5	48.8	58.8	31.2
75µm	46.0	23.00	81.8	14.8
Pan	29.6	14.8	_	_
Total			150.6	

The fineness modulus (FM) of SDA is computed as 1.51 from table 1, which is less than FM of 2.3-2.1 for fine aggregate specified in [28] hence SDA is finer than fine aggregate.

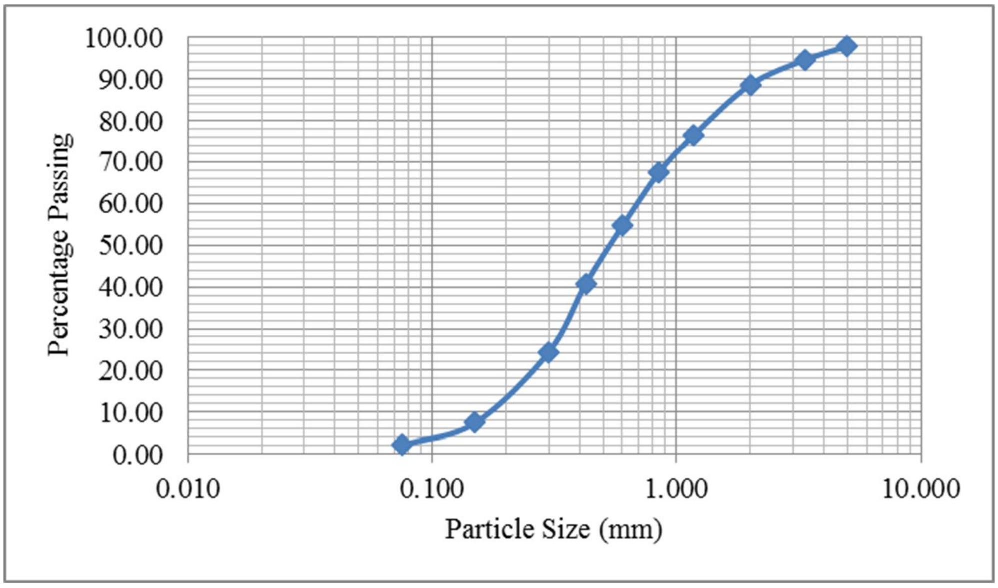

Figure 1. Particle size distribution of fine aggregate

From the particle size distribution Curve in figure 1, grain size corresponding to 60% (D_{60}), 10% (D_{10}) and 30% (D_{30}) passing through the sieve is 0.75mm, 0.1mm and 0.37mm respectively. The uniformity coefficient C_u is calculated as equal to 7.0, while the coefficient of curvature C_c is calculated as 1.63. This indicates that Sand is within specifications, a well-graded sand, which agrees with the unified soil classification system (USCS) conforming where Cu ≥ 6 and $1 \leq Cc \leq 3$ [29].

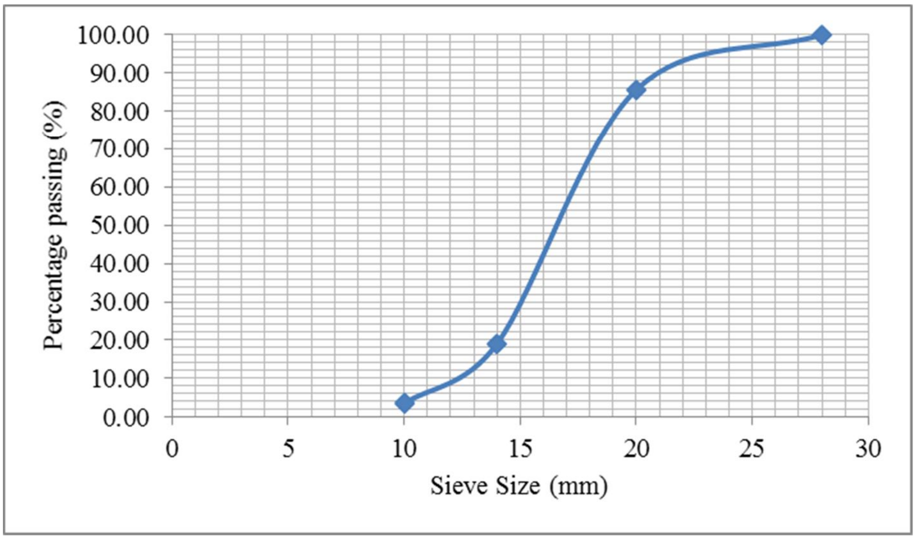

Figure 2. Particle size distribution of coarse aggregate

From the particle size distribution of coarse aggregate (Figure 2), grain size corresponding to 60% (D_{60}), 10 % (D_{10}) and 30% (D_{30}) passing the sieve is 17.4mm, 12.5mm and 15mm respectively. Therefore, uniformity coefficient C_u is calculated below = 1.39. Coefficient of Curvature, Cc is calculated = 1.04. Hence the aggregate is well graded since the result agrees within a well graded sand with less than 5% fine which has 1$\leq Cc \leq 3$ [29].

Specific gravity: The specific gravity of SDA was 2.51 through an average of two trials. The fine aggregate have a specific gravity of 2.65 also through an average of two trials falling within the limit for natural aggregates with value of specific gravity between 2.6 and 2.7 as recommended [23]. The average specific gravity of coarse aggregate was 2.63 through two trials. The value of specific gravity of SDA is, however, less than the value of cement, 3.15.

Bulk density: The values for compacted and un-compacted bulk densities of SDA were 155.1kg/m^3 and 167.1kg/m^3 respectively. While the calculated values for the compacted and un-compacted bulk densities of the sand were 2.77g/m^3 and 2.48g/m^3.

Moisture content of Fine Aggregate: The free moisture content test result was found to be 0.044%. This was the amount of water content in the sand before its use for concrete work.

Chemical analysis of SDA

The chemical composition of SDA used in this study is presented in Table 2. The oxides: Silicon dioxide (SiO_2=27.228%), Iron oxide (Fe_2O_3=9.322%) and Aluminium Oxide (Al_2O_3 =29.052%) which constitute a total sum of 65.602% of pozzolanic materials is slightly below 70% but greater than 50% specified by ASTM C 618 [28] for pozzolana. The classification is based on the summation of the basic oxides (SiO_2 + Fe_2O_3 + Al_2O_3=65.602%): if the sum is greater or equal to 70% then the ash is classified as Class F, while if it is greater than or equal to 50% it is class C. From this result, the SDA is a pozzolanic material and falls under class C [6 – 7, 28].

Table 2. Chemical Composition of SDA

Element	Compound formed	Percentage (%)
Si	SiO_2	27.23
Ca	CaO	32.42
Al	Al_2O_3	29.05
Mg	MgO	6.72
Fe	Fe_2O_3	9.32
Na	Na_2O	4.91
Mn	Mn_2O_3	0.00
K	K_2O	6.88
P	P_2O_5	5.89
S	SO_3	0.00
Ti	TiO_2	1.00
Zn	ZnO	0.00
Cr	Cr_2O_3	0.00

From Table 2 the results show higher values for major oxides compared to the minor oxides except for NaO, MgO K_2O and P_2O_5 that equally exhibit slightly higher content. The SiO_2 shows higher composition, which indicates that the SDA is in the range of amorphous phase (greater than 50%).

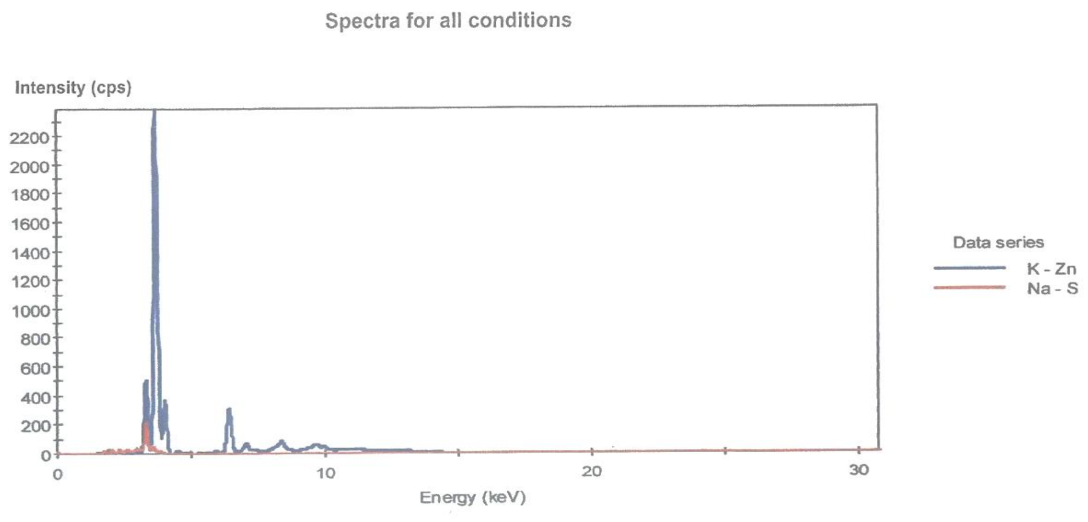

Figure 3. XRF Profile of Saw Dust Ash with evidences of amorphous phases of SiO_2

Slump Value and compacting factor test

The results of slump test for the concrete beam are shown in Table 3. The slump is a measure of workability of the concrete. The variation of slump value when cement is partially replaced with SDA depicts the demand of water. As the ash content increases, the slump reduces thus giving rise to lower workability.

The compacting factors shown in Table 4 reduce as the SDA content increases. The values reduced from 0.91 to 0.81 as the percentage SDA replacement increased from 0% to 20% for the re-vibrated beams. These results indicate that the concrete becomes less workable (stiff) as the SDA percentage increases meaning that more water is required to make the mixes more workable. The high demand for water as the SDA content increases is due to increased amount of silica in the mixture. This is typical of pozzolana cement concrete as the silica-lime reaction requires more water in addition to water required during hydration of cement [30]. The compacting factor for concrete mortar varies between 0.81 and 0.90.

Table 3. Slump test for revibrated beams

S.No	Specimens	Replacement level (%)	Slump value(mm)
1	M	0	34
2	N	5	19
3	O	10	18
4	P	15	14.5
5	Q	20	no slump

Table 4. Compacting factor for the beams

S.No	Specimens	Replacement level (%)	Compacting factor
1	M	0	0.91
2	N	5	0.90
3	O	10	0.87
4	P	15	0.83
5	Q	20	0.81

Flexural strength of revibrated and non- revibrated concrete beams with SDA at 28 days

The experimental setting for the flexural strength of the beam specimens is shown in figure 5a. The results of the flexural test for the fifty beam specimens are presented on Tables 5 (for non-revibrated), 6 for re-vibrated), 7 (for re-vibrated and non-revibrated at 20minutes) and figure 4 (for re-vibrated). The maximum flexural strength was 8.87N/mm^2 at 0% replacement for the non – revibrated beams, while at 20 minutes re-vibration time lag, 10N/mm^2 and 9.5N/mm^2 were attained as maximum for 0% and 5% replacements of SDA for cement respectively. Generally, the flexural strength is seen decreasing as the percentage of SDA increases.

From table 6, there is significant increase in the flexural strength from 0 to 20 minutes revibration time lag and decrease in the flexural strength from 30 to 60 minutes within the same replacement from 0% to 20%. The trend is clearer on table 7 where the values of re-vibrated beams at 20minutes time lag are compared with value obtained from non-revibrated beams. This appreciable and significant increase in the flexural strength of the beams at early stages of re-vibration from 0 minutes to 20 minutes and gradual drop from 30 minutes to 60 minutes is graphically presented in Fig. 4. Thus showing that revibration is the main factor responsible for the significant increase of the flexural strength.

Furthermore, the early increase in flexural strength may be attributed to the calcium hydroxide in the OPC and revibration which enhanced densification and volumetric compaction of the concrete beam, but later re-vibration will de-bond the chemical compound of C_3S which lead to decrease in strength from 30 minutes to the elapsing of an hour. Revibration seems to have improved the flexural strength of a reinforced concrete beams from early revibration up to 20 minutes.

The behavior and mode of failure of the beam in response to load is presented figure 5b and 5c shows that as the pressure increases, a diagonal and hair-like crack was observed which starts from the point of load towards the support. The crack starts from the zone of tension to compression then fails which is similar to any failing beam.

Table 6. Flexural strength of re-vibrated beams after 28 days curing

S.No.	Percentage replacement for SDA (%)	Flexural Strength at each re-vibration time lag, N/mm².						
		0 mins	10 mins	20 mins	30 mins	40 mins	50 mins	60 mins
1	0	9.6	9.6	10	9.0	8.0	7.5	7.0
2	5	9.0	9.8	9.5	8.5	7.8	7.0	7.0
3	10	7.0	7.0	7.5	7.0	6.0	5.5	5.5
4	15	5.0	5.5	5.5	5.0	5.0	5.0	5.0
5	20	3.5	4.0	4.5	4.0	4.0	4.5	4.0

Table 5. Flexural strength of non-revibrated beams after 28 days curing

S.No.	Specimen	Percentage replacement (%)	Weight	Flexural strength (bar)	Flexural strength (N/mm²)	Average flexural strength (N/mm²)
1	A	0	32.90 32.79 33.00	88 90 88	8.8 9.0 8.8	8.87
2	B	5	33.20 33.10 33.28	70 60 70	7.0 6.0 7.0	6.67
3	C	10	33.50 33.75 33.00	60 55 53	6.0 5.5 5.3	5.6
4	D	15	34.00 33.86 33.45	45 40 40	4.5 4.0 4.0	4.2

Table 7. Flexural strength of revibrated and non-revibrated beams at 20 minutes time of revibration

S. No.	Item	Percentage replacement for SDA				
		0%	5%	10%	15%	20%
1	Maximum flexural strength of revibrated beams at 20 minutes revibration	10	9.5	7.5	5.5	4.5
2	Flexural strength of non-revibrated beams	8.87	6.67	5.6	4.2	5.0

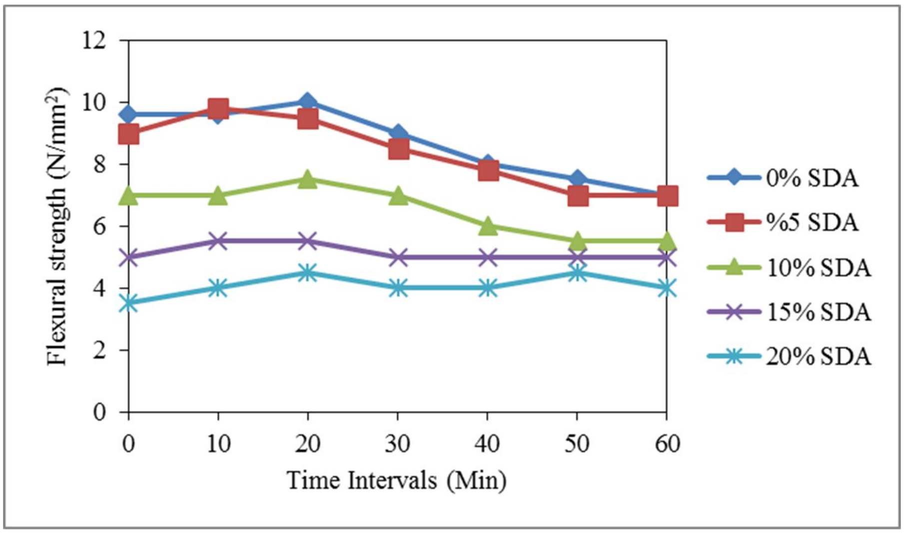

Figure 4. Effect of revibration on the flexural strength with re-vibration time lag for all percentages

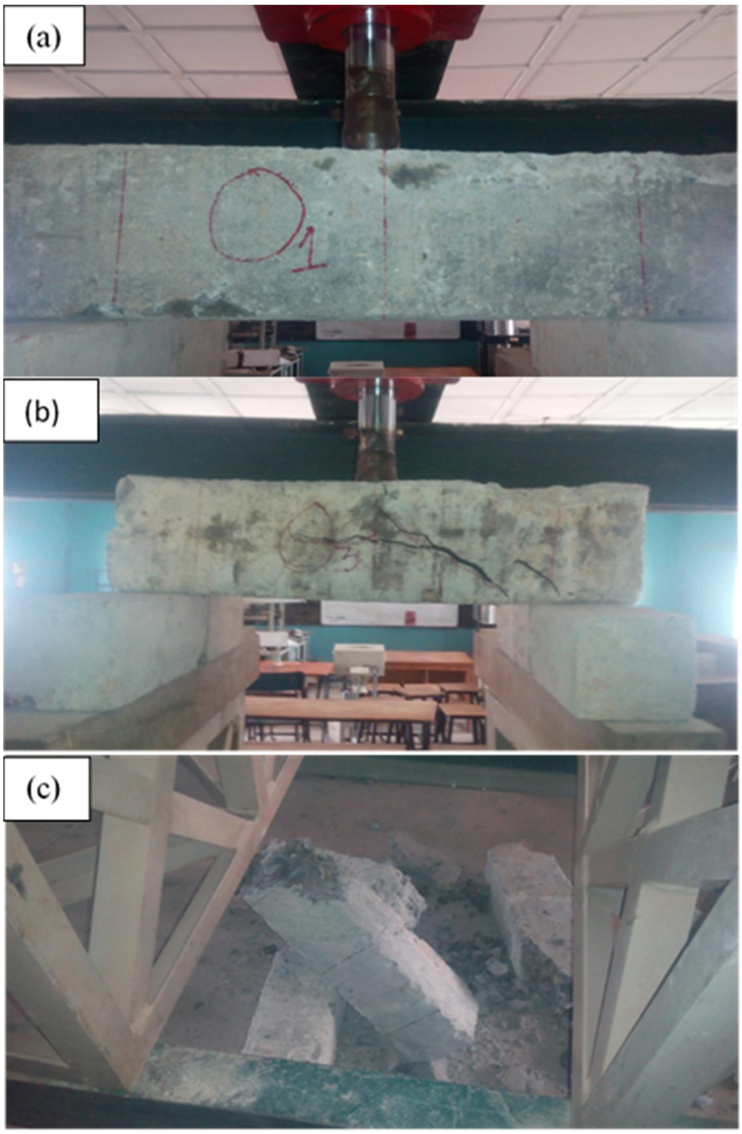

Figure 5. (a) Experimental setting for flexural test, (b) failure mode of the beam specimen, (c) crushed beam

5. Conclusion and Recommendations

The following conclusions are drawn:

- Chemical analysis of SDA indicated that the major constituents of SDA includes; calcium oxide (CaO), Silicon dioxide (SiO_2), iron oxide (Fe_2O_3) and Aluminium Oxide (Al_2O_3) and other minor oxides place SDA in C class of pozzolana, where Al_2O_3 + SiO_2 + Fe_2O_3 = 65.602% slightly lower than 70% as specified for pozzolana [28].
- The Fineness Modulus of SDA was 1.51, which is similar to the Fineness Modulus result of 1.38 [31];
- The flexural strength of concrete with 5% SDA replacement of cement is slightly less than that with 0% SDA (control) for the revibrated beams but still higher than that control specimen (0% SDA) of non-revibrated concrete beam.
- The flexural strength of revibrated concrete beam significantly decreases as the percentage SDA surpasses 5% and the revibration period exceeds 20minutes. Therefore, up to 5% sawdust Ash can be used as replacement of cement in concrete.
- The flexural strength of non-revibrated SDA concrete significantly, decreases at virtually all percentage level of SDA, replacement of cement should be followed by revibration up to 20 minutes.

Recommendations

Based on the experimental works the following recommendations are made:

- The process of re-vibration should generally be encouraged in concrete production in other to ensure concrete quality.
- Addition of up to 5% SDA to concrete should be followed by revibration up to 20minutes in order to improve the strength.
- Sawdust should be properly burnt and the chemical composition of the ash be determined before it is used in concrete work
- More research is recommended on the chemical analysis of Sawdust Ash from different wood species to investigate its appropriateness for use in concrete production.

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Прочность при изгибе железобетонной балки с золой древесных опилок в качестве частичной замены цемента

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АННОТАЦИЯ

В статье представлено исследование прочности при изгибе железобетонной балки с золой древесных опилок (ЗДО) в качестве частичной замены цемента, подвергнутого повторной вибрации. Химический анализ образца ЗДО содержит следующие основные химические оксиды: SiO_2 от (27.23%), Al_2O_3 (29.05), Fe_2O_3 (9.32%). Семь образцов балки с размерами 150 мм x 150 мм x 600 мм, армированные стальными стержнями с диаметром 12 мм (Y12) были изготовлены для каждого процентного отношения замены цемента (0, 5, 10, 15 и 20%). Балки подвергались повторной вибрации в течение 20 секунд с интервалом от 10 минут до 1 часа после первоначальной вибрации. Еще один набор из трех балок, имеющих одинаковый размер и армирование, был отлит, но не подвергнут повторной вибрации. Всего было подготовлено пятьдесят балок, в том числе: тридцать пять подвергались повторной вибрации и пятнадцать не были подвергнуты повторной вибрации. Образцы были выдержаны 28 дней. Полученные результаты прочности при изгибе после испытания каждой балки показывают максимальную прочность при изгибе при 0% замены для балок, подвергнутых повторной вибрации. Следующим результатом по прочности является образец с 5% заменой цемента. Максимальная прочность на изгиб достигла 10Н/мм2 при 0%, и 9,5 Н/мм2 при 5% соответственно, для балок, подвергнутых повторной вибрации, а для балок, не подвергнутых повторной вибрации - 8.87 Н/мм^2 и 6,67 Н/мм^2 при 0 и 5% замены. Таким образом, повторная вибрация улучшает прочность при изгибе железобетонных балок и, ЗДО могут быть использованы до 5% замены цемента.

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