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Civil Engineering

EFFECT OF REVIBRATION ON THE FLEXURAL STRENGTH OF CONCRETE USING MAHOGANY SAWDUST ASH AS A PARTIAL REPLACEMENT FOR CEMENT

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Abstract

Introduction: The paper addresses the effect of revibration on the flexural strength of reinforced-concrete beams using mahogany sawdust ash (MSDA) as a partial replacement for ordinary Portland cement (OPC). Beam specimens of sizes 150 mm x 150 mm x 600 mm reinforced with 12 mm diameter steel bars (Y12) and 8 mm diameter steel bars (Y8) as links, were used to cast each of 0%, 5%, 10%, 15% and 20% replacements of cement for SDA. The beams were revibrated after the initial vibration for 20 s at 10-minute successions within one hour. Fifty beams were cast in total and cured for 28 days: 35 revibrated and 15 non-revibrated. **Methods**: Based on the chemical analysis of MSDA, the following major chemical oxides were found in cement: SiO2 (39.87%), Al2O3 (18.05%), Fe2O3 (6.92%). Flexural strength tests were carried out for each beam using the three-point load method, and the result shows that the peak flexural strength occurred at 0% followed by 5% replacement at the 20-minute revibration time interval. The revibrated beams show the peak flexural strength of 10.50 N/mm2 and 10.00 N/mm2 at the 20th minute for 0% and 5% replacements; for the non-revibrated beams, 8 N/mm2 and 7 N/mm2 were obtained for 0% and 5% replacements, respectively. **Results:** According to the flexural strength test results, revibration has improved the flexural strength of the concrete beams produced, and MSDA as pozzolana is recommended to comfortably replace cement by not more than 5%.

Keywords

Flexural strength, reinforced-concrete beam, revibration, MSDA.

Introduction

The rising cost of traditional building materials (especially, cement) and the devaluation of local currencies of developing nations, makes it difficult for low income earners to own a private house. Those factors have also complicated the construction of civil engineering infrastructure required for national development (Onwuka et al., 2013).

Continuous generation of wastes arising from industrial by-products and agricultural residue create acute environmental problems both in terms of their treatment and disposal. The construction industry has been identified as the one that absorbs the majority of such materials as filler in concrete (Antiohos et al., 2005). 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 (Hossain, 2003). Much less attention is placed on revibration and its importance in concrete production, the process whereby a vibrator is reapplied to concrete at some interval of time after the initial vibration has been carried out (Auta, 2011). A pozzolana is a material which, when combined with calcium hydroxide, exhibits cementitious properties. Pozzolanas are commonly used as an admixture to Portland cement concrete mixtures to increase the long-term strength and other material properties of Portland cement concrete and in some cases reduce the material cost of concrete. Pozzolanas are primarily vitreous siliceous materials which react with calcium hydroxide to form calcium silicates; other cementitious materials may also be formed depending on the constituents of the pozzolana.

Sawdust ash (SDA) is a waste material from the timber industry. It is produced from logs of timber sawn into planks at sawmills located in virtually all major towns in the country. This process is a daily activity causing heaps of sawdust to be generated after each day. The need to convert this waste product into a useful by-product is the focus of this study (Osey and Jackson, 2012). Some industrial wastes have been studied for use as supplementary cementing materials such as: fly ash (Mathong, 2012); silica fume (Raheem et al., 2012); volcanic ash (Hossain, 2005); rice husk ash (RHA) and corn cob ash (CCA) (Raheem and Adesanya, 2011).

Auta, Abanda and Tsado (2015) and Auta, Amanda, and Sadiku (2015), stated in their findings that flexural strength of RHA concrete increases at the early stage of revibration, the flexural strength of RHA concrete decreases from 30 minutes to 60 minutes of revibration almost for all percentage replacement level of RHA.

Flexural strength of structural elements may be said to be its resistance to bending 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.

According to published findings of researchers, the focus is made on SDA (Auta et al., 2016), which is represented by combinations of different wood species. However, different wood species have different characteristic strengths (Aguwa, 2016). Thus, in this paper, mahogany was determined as a wood species with considerable characteristic strength and hence chosen to produce mahogany sawdust ash (MSDA).

MATERIALS AND EQUIPMENT

Materials

The materials used in this study include:

Fine Aggregate

The fine aggregate (sand) used was clean sharp river sand free of clay, loam, dirt, and any organic or chemical matter, passed through 5 mm British Standard test sieves. It conformed to BS EN 12620 (2013) requirements.

Coarse Aggregate

The coarse aggregate used was gravel free of particles, passed through 10–14mm British Standard test sieves. Quarry gravel was bought from Kpakungu in Minna, Niger State, Nigeria. It conformed to BS EN 12620 (2013) requirements.

Mahogany Sawdust Ash (MSDA)

The sawdust ash was obtained from mahogany wood species sourced from the Dei-Dei timber shed near the Kubwa–Abuja expressway, transported to Minna, sun-dried and then burnt at a controlled temperature of 800°C.

Water

The water used to mix the concrete during this study was free from organic materials and suspended debris. It was obtained from a borehole near the Civil Engineering Laboratory of the Federal University of Technology, Minna. It also conformed to BS EN 1008 (2002) requirements.

Steel Reinforcement

For each specimen, two 12 mm steel bars (Y12) were used as tension bars and two 12 mm steel bars were used as compression bars. 8 mm links were used as well.

Equipment

The equipment used during the study included: a weighing machine, British standard sieves, a head pan, a hand trowel, a tamping rod, buckets, a poker vibrator, a beam mold (150 mm x 150 mm x 600 mm) and a universal testing machine for the flexural strength test of cured beam specimens.

EXPERIMENTAL PROCEDURES

Procedures

The experimental procedures adopted in this study included the following:

Chemical analysis of MSDA: The chemical analysis of mahogany sawdust ash was conducted at a chemical laboratory where the oxides' composition was determined using X-Ray fluorescent (XRF) tests. This technique was used to discover in-depth information about the chemical composition of MSDA.

Aggregate characterization: The aggregates used for this study were tested for their physical properties such as specific gravity, particle size distribution (sieve analysis) and bulk density.

Preparation of beam specimens: Fifty rectangular beam specimens of 150 mm x 150 mm x 600 mm were produced for the study. Their batching and casting were carried out using the absolute volume method in accordance with BS 1881: part 2 (1970), with a concrete mix ratio of 1:2:4, and a water/cement ratio of 0.5. The main reinforcement used was 12 mm (Y12) diameter tensile steel and the links provided were represented by 8 mm (Y8) bars placed at regular spacing of 125mm c/c. Beam specimens of two types were produced: revibrated and non-revibrated. As for the revibrated beams, 35 beams were produced for percentage replacements (0%, 5%, 10%, 15%, and 20 %) of OPC for MSDA. For each of these percentage replacements, seven beams were cast. The revibration process lasted 20 s at 10-minute successions within one hour. As for the non-revibrated beams, three beam specimens were produced for each percentage replacement to make a sub-total of 15 non-revibrated beams. A poker vibrator was used to compact the concrete mix in the mold for both initial vibration and revibration processes. The beams were de-molded after 24 hours and cured for 28 days. Then, they were tested for flexural strength using a universal testing machine (UTM).

The bending strength test conducted on concrete beams satisfied the requirements of BS 1881-116 (1983) for flexural testing of beams, using the three-point center-point load method as shown in Figure 4. The samples were placed correctly centered, with the longitudinal axis of the beam aligned at a right angle to the supporting and load-applying rollers. This ensured that the top and bottom surfaces of the beam were parallel and the loading was uniform across the width of the beam.

Results and discussion

The laboratory test results included: chemical analysis of MSDA, aggregate characterization, tests on both fresh and hardened concrete. The results are presented in Tables 1, 2, 3, 4, 5, 6 and Figures 1, 2, 3, 4.

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Chemical analysis of MSDA: The chemical composition of MSDA used in the study is presented in Table 1. The chemical composition includes: silicon dioxide (SiO_2 = 39.873%), iron oxide (Fe_2O_3 = 6.924%), and aluminium oxide (Al_2O_3 = 18.053%), which constitute a total sum of 64.84%, which is slightly below 70% but greater than 50% for a pozzolanic material.

The fly ash, which can be potentially used for concrete, is classified into classes C and F (ASTM C618-19, 2019). The classification is based on the following: if the sum of the three oxides (SiO_2, Fe_2O_3 and Al_2O_3) above is 70%, the ash is classified as class F, while if the sum 50%, it is classified as class C. In this study, MSDA (a pozzolanic material) falls under class C (ASTM C618-19, 2019).

Table 1. Chemical composition of MSDA

Element	Concentration
Na_2O	1.012
MgO	6.905
Al_2O_3	12.046
SiO_2	49.054
P_2O_5	2.017
SO_3	3.212
Cl	2.412
K_2O	1.224
CaO	11.125
TiO_2	1.562
Cr_2O_3	0.000
Mn_2O_3	0.198
Fe_2O_3	8.935
ZnO	0.209
SrO	0.125

Aggregate characterization: The aggregates and MSDA were tested for specific gravity, particle size distribution, and bulk density.

Particle size analysis for fine, coarse aggregates and MSDA: The results of particle size distribution of MSDA, coarse and fine aggregates used in this study are presented in Table 2, Figures 1 and 2, respectively.

Coarse aggregate particle size analysis: According to Figure 1 below, the grain size corresponding to 60% (D_{60}), 10% (D_{10}) and 30% (D_{30}) is 10.5 mm, 10.1 mm and 10.3 mm, respectively. Therefore, the uniformity coefficient Cu is calculated as equal to 1.04, while the coefficient of curvature Cc is calculated as equal to 1.003. C_u<4 and 1 ≤ Cc << 3 indicates that the gravel is poorly graded in accordance with unified soil classification system (USCS). Therefore, it can be classified as GP.

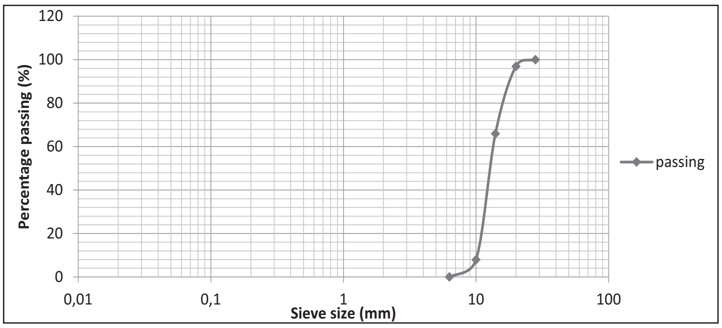

Figure 1. Particle size distribution of coarse aggregate

Fine aggregate particle size analysis: According to Figure 2 below, the grain size corresponding to 60% (D_{60}), 10% (D_{10}) and 30% (D_{30}) is 0.95 mm, 0.35 mm and 0.59 mm, respectively. Therefore, the uniformity coefficient Cu is calculated as equal to 2.70, while the coefficient of curvature Cc is calculated as equal to 1.05. C_u<4 and 1 ≤ Cc << 3 indicates that the sand is poorly grained sand according to the unified soil classification system (USCS). Therefore, it can be classified as SP.

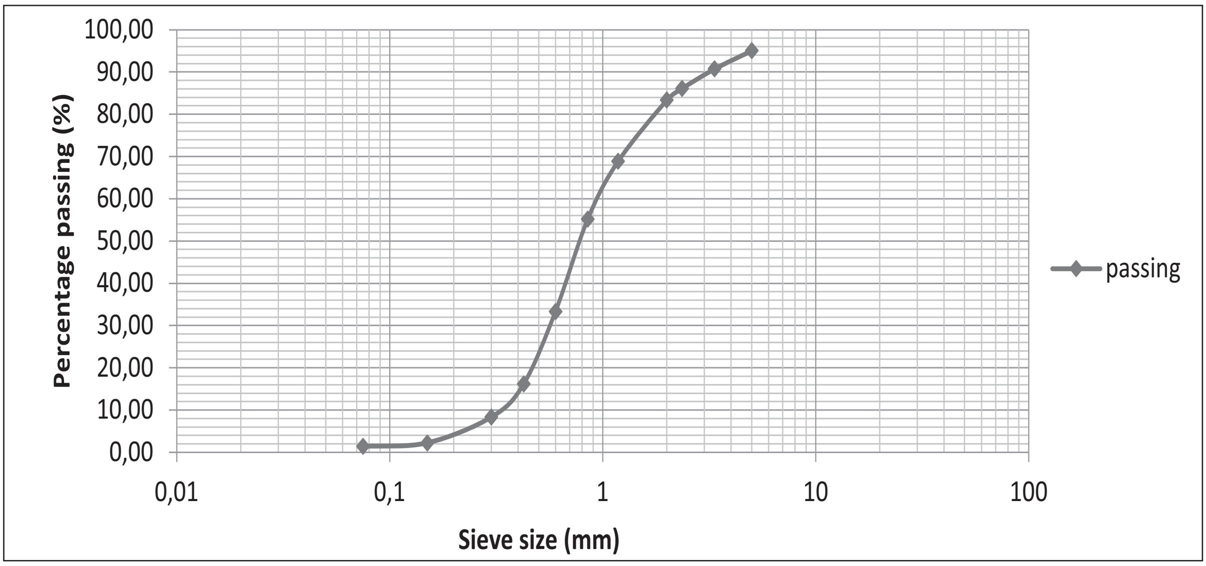

Figure 2. Particle size distribution of fine aggregate

Mahogany sawdust ash particle size analysis

According to Table 2, the MSDA fineness modulus (FM) is obtained as equal to 1.51. The fineness modulus of 1.51 is less than the fineness modulus of 2.1–2.3 for fine aggregate suggested by American Society for Testing and Materials (ASTM) C 33, hence, MSDA is finer than the fine aggregate.

Table 2. MSDA particle size analysis

Sieve size (mm)	Sample weight retained (g)	Percentage retained (%)	Cumulative percentage retained (%)	Cumulative percentage passing (%)
0.850	0.00	0.00	0.00	0.00
0.600	0.00	0.00	0.00	0.00
0.425	0.00	0.00	0.00	0.00
0.300	22.20	11.10	11.10	88.90
0.150	95.68	47.84	58.94	41.06
0.075	44.39	22.19	81.13	18.87
Pan	36.55	18.27	-	-
Total			151.17	

Specific gravity test of aggregates and MSDA: The specific gravity of MSDA, fine and coarse aggregates is 2.62, 2.65 and 2.63, respectively. Each test was performed thrice with the same sample and the mean specific gravity of each sample was taken. However, the specific gravity of MSDA is less than the specific gravity of cement of 3.15.

Bulk density test of aggregates and MSDA

The compacted and un-compacted bulk densities of MSDA are 478.91Kg/m^3 and 455.88Kg/m^3. The compacted and un-compacted bulk densities of coarse aggregate are 1668.82Kg/m^3 and 1589.99Kg/m^3 and those of fine aggregate are 1534Kg/m^3 and 1352Kg/m^3.

Slump test and compacting factor test of fresh MSDA-cement concrete

Slump test: The slump test results for the fresh concrete beams are presented in Table 3 below. The difference between the standard cone height and the height of concrete after slump gives the slump value. Table 3 also shows the variation of slump values when cement is partially replaced with MSDA in concrete. The slump value decreases with increasing percentage replacement of OPC with MSDA; this is due to the high demand for water as the ash content increases leading to low workability.

Compacting factor test: The compacting factor test results are presented in Table 4. The table shows that the compacting factor values decrease as the MSDA content increases. The compacting factor values decreased from 0.92 to 0.84 as the percentage of MSDA replacement increased from 0% to 20% for the revibrated beams. The high demand for water as the MSDA content increased was due to an increase of silica in the mixture. This is different in the case of pozzolana cement concrete as the silica-lime reaction requires more water in addition to water required during hydration of cement (Auta et al., 2016).

Table 3. Slump test results for the fresh concrete beams (w/c = 0.5)

No.	Percentage replacement for MSDA (%)	Slump (mm)
1	0	25
2	5	19
3	10	16.5
4	15	14
5	20	No slump

Table 4. Compacting factor test results for the fresh concrete beams

No.	SDA percentage replacement (%)	Compacting factor value
1	0	0.92
2	5	0.88
3	10	0.87
4	15	0.86
5	20	0.85

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Effect of revibration on the flexural strength of the revibrated and non-revibrated beams at 28 days curing: Table 5 and 6 show the results of the flexural strength test of each beam specimen for the revibrated beams over time and for the non-revibrated concrete beams, respectively. The mean flexural strength of the control specimen is 9.29 N/mm^2, which is higher than 5% replacement of MSDA with OPC of 8.93 N/mm^2 after 28 days curing. The overall mean flexural strength of the specimen reduces from 8.93 N/mm^2 to 4.79 N/mm^2 for 5% to 20% replacement of MSDA with OPC. The peak flexural strength for the revibrated and non-revibrated beams was 10 N/mm^2 at 20th minutes of revibration (Table 5) and 7.0 N/mm^2 (Table 6) for 5% replacement, respectively. Table 5 shows that the flexural strength increased significantly from the 0th to 20th minutes of revibration and decreased from the 30th to 60th minutes within the same percentage replacements, indicating that revibration reduced the flexural strength of concrete.

Table 5. Flexural strength of the revibrated concrete beams at 28 days curing

No.	Percentage replacement for MSDA (%)	Flexural strength at each revibration time lag, N/mm^2							Mean flexural strength (N/mm^2)
		0th min	10th min	20th min	30th min	40th min	50th min	60th min	
1	0	9.5	10.0	10.5	9.5	9.0	8.5	8.0	9.29
2	5	9.0	9.5	10.0	9.5	9.0	8.0	7.5	8.93
3	10	7.5	7.5	8.0	8.5	8.0	7.5	7.0	7.71
4	15	6.5	7.0	7.5	7.0	6.5	6.0	6.0	6.64
5	20	4.0	4.5	5.0	5.5	5.5	4.5	4.5	4.79

Table 6. Flexural strength of the non-revibrated beams at 28 days of curing

No.	Percentage replacement for MSDA (%)	Weight of specimen (kg)	Density of specimen (kg/m^3)	Flexural strength of specimen		Mean flexural strength (N/mm^2)
				bar	(N/mm^2)	
1	0	34.92	2586.67	80	8.0	8.0
		34.24	2536.30	85	8.5	
		35.05	2596.30	75	7.5	
2	5	33.02	2445.93	70	7.0	7.0
		33.05	2448.15	75	7.5	
		33.10	2451.85	65	6.5	
3	10	34.90	2585.19	65	6.5	6.2
		34.85	2581.48	60	6.0	
		34.54	3558.52	60	6.0	
4	15	36.31	2689.63	45	5.5	5.3
		34.65	2566.67	50	5.0	
		33.86	2508.15	55	5.5	
5	20	33.21	2460.00	45	4.5	4.7
		33.87	2508.89	50	5.0	
		32.63	2417.04	45	4.5	

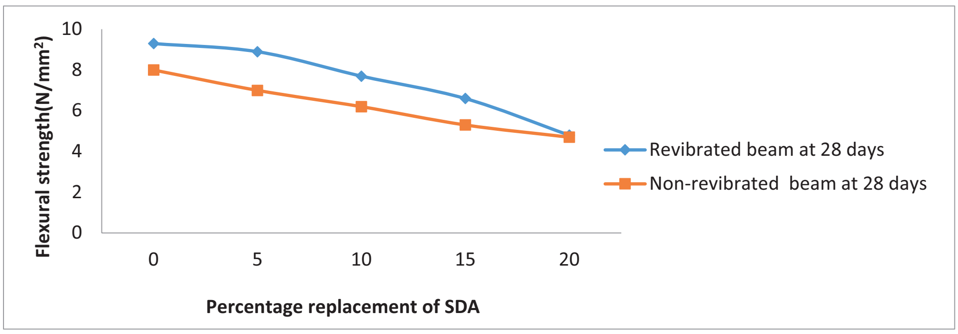

Figure 3. Flexural strength of the revibrated and non-revibrated beams at 28 days curing

Figure 4. Flexural testing of a beam

In Figure 3, the flexural strength values for the revibrated and non-revibrated beams are compared. It clearly indicates that the values for the revibrated beams are higher than those for the non-revibrated ones. This demonstrates the positive effect of revibration on the flexural strength of reinforced MSDA–cement concrete beams. However, the general flexural strength decreases with an increase of MSDA.

Conclusion and recommendations

Conclusion

The effect of revibration on the flexural strength of reinforced-concrete beams using mahogany sawdust ash (MSDA) as a partial replacement for ordinary Portland cement (OPC) is presented. Based on the study, the following conclusions can be drawn:

1. The major constituents of SDA (based on the chemical analysis) include: Al_2O_3, SiO_2, and Fe_2O_3, whose percentage sum of 64.84% is nearly 70% as stipulated by ASTM C 618 (1991) and indicates that MSDA obtained belongs to class F pozzolana.
2. The mean flexural strength values for the revibrated and non-revibrated beams compared clearly indicate that the values for the revibrated beams are higher than those for the non-revibrated demonstrating the positive effect of revibration on the flexural strength.
3. The maximum flexural strength was obtained at the 20th minute of revibration for both 0% and 5% replacements. Others were low both at revibration time intervals and percentage replacements.
4. The compacting factor and flexural strength values decrease as the percentage replacement of SDA increases.

Recommendations

Based on this study, the following recommendations can be made:

The sawdust should be properly assembled, differentiated from other sawdust obtained from other wood species, sun-dried, and burnt; and the chemical analysis of the sawdust should be performed before it is used in concrete production.

The revibration process can always be employed in concrete production to improve the quality of concrete and, when treated with MSDA, 5% replacement of cement should not be exceeded; moreover, revibration beyond 20 minutes is not recommended.

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