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Production of sustainable concrete using sawdust

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Abstract. Rapid progression of construction industry rises the demand on building materials. With focusing on developing cost effective, sustainable and eco-friendly buildings, there is a need to find alternative materials to fulfil the constructions' requirements. This paper presents an experimental study to investigate the applicability of using sawdust and sawdust ash as a green alternative for natural sand and cement respectively in order to lessen both environmental impacts and construction cost. The proposed mixtures incorporate sawdust with 5 %, 10 %, 15 %, 20 %, 25 % and 30 % as partial substitution for each of natural sand and cement. Mechanical properties of proposed mixes were compared to reference mixtures with typical concrete constituents. Physical properties were also investigated. The test results reveal that the optimum percentage of replacement of natural sand for producing sawdust concrete mixture is 10 % to 20 % and the acceptable percent of partial replacement of cement with sawdust ash is up to 15 %.

1. Introduction

Sustainable development is related to balance in maintaining resources, energy and solving environmental problems. It is becoming progressively well-defined that incorporation of sustainable practices and methodologies into civil engineering is crucial for the sustainability of the environment [1]. Concrete is acknowledged for being the basic material used in construction based on its ability to be cast in different geometrical structures, less maintenance requirements, and good durability and mechanical properties. However, different gases, especially CO_2, are discharged tremendously during production of its constituents which is considered a global concern. In addition, it is categorized as an excessive energy ingestion industry. Furthermore, the essential reliant of concrete on the availability of natural resources such as sand, which is utilized as fine aggregate, causes growing scarcity of sand and eco-system disruption. This imposes researchers to yield novel materials from renewable sources to be used in construction to mitigate the effect of building industry on environment.

Natural fibers and industrial and agricultural wastes, with their renewable and sustainable nature, are increasingly applied in construction. Previous research specified that natural fiber provides considerable reduction in weight of structure, improves sound absorbent properties owing to its excessive void ratio, facilitates handling, mixing and placing of mixtures competed to other types of concrete [2–3]. It is also recognized by its low production cost, less health hazards, and accessible processing [2–3].

An equally significant direction is the usage of industrial wastes in producing of building materials with low density, sound and heat conductivity, as well as high physical and mechanical properties. These materials are used in casting cellular concrete for constructing the external and internal walls of buildings [4–5]. Several studies describe the compositions and technology for producing cellular concrete from lightweight geopolymers as an example of industrial wastes [6–13].

The implementation of fillers which can be represented as particles of the dispersed phase change the energy state of the dispersed system [14–18]. The used fillers depend on their chemical activity. Efficient fillers have a multifunctional usefulness in the synthesis of materials through forming a denser packaging

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of the initial components and changing the chemistry of the binder hardening [19–23]. Granulated blast furnace slag, silica fume, fly ash, and rice husk ash [24–27] are considered suitable alternatives for partial replacement of cement. While recycling concrete, crushed steel, and expanded perlite symbolize good alternatives for aggregates [28–31].

Another direction is the technology of modifying the structure of concrete by introducing into the concrete mixture the porous dispersed components (damping additives). This method of increasing the shock endurance of concretes was researched by R. Oyguc [32], M. Kristoffersen [33], A. Maazoun [34], Z.I. Syed [35], and K. Makita [36]. However, these concretes provide a relatively moderate increase in shock endurance – up to 2–4 times, which is not sufficient for protective structures in conditions of the action of the means of destruction, which create high dynamic loads on the enclosing structures.

The use of fiber-reinforced concrete for the production of enclosing structures of protective structures is promising because it has high impact resistance [37–46]. Dispersed reinforcement allows to substantially increase the whole set of mechanical characteristics of concrete, such as static strength, crack toughness, impact resistance.

Sawdust, collected from grinding, cutting, or pulverizing of hard and soft woods is an example of natural fiber. Sawdust has been used, but not widely, as fine aggregate in casting floors, roofs and walls for more than 50 years. Recently, some researcher investigated the applicability of using wood waste as a replacement for fine aggregate in concrete mixtures [47–51]. Turgut [52] postulated that it can be used efficiently in producing artificial limestone brick. Researchers [53–54] suggested that wood chipping improves the thermal and insulation properties of concrete mixtures and lessen the density of the concrete, however, it attained high water absorption [53]. Coatanlem et al [55]. Boob [56] investigated the effect of replacing 15 % of sand with sawdust in casting blocks for partition walls in multi-storey building using 1:6 cement and sand mix. His results reveals that the compressive strength for these blocks was 4.5 N/mm^2 which is considered reasonable and economic for this application. Compressive strength, flexural strength, ultrasonic pulse velocity (UPV), unit weight and water absorption of lightweight composite consists of combinations wood sawdust waste and limestone powder wastes were assessed by Turgut and Algin [57]. They found values for tested properties are in accordance to International Standard (IS). On assessing the effect of sawdust on compressive strength at 28 days, Paramaswam et al. [58] argued that for mixtures with cement to sawdust ratio of 1:1, 1:2, and 1:3, the compressive strengths were 31, 8.5, and 5 N/mm^2 respectively. Jr. [59] and Osei and Jackson [60] found that the strength of sawdust concrete decrease as water-cement ratio is less than 0.45.

The aim of this paper is to demonstrate the potential of using sawdust wastes in order to produce the desired composite and sustainable green construction material. Natural fine aggregate and cement is substituted by sawdust at percentages 5, 10, 15, 20, 25 and 30. Experimental investigations on physical and mechanical properties of concrete made with sawdust were conducted and compared to control mix cast with typical concrete constituents.

2. Methods

The experimental work was premeditated to assess the effect of fractional replacement of natural sand and cement with sawdust and sawdust ash respectively on physical and mechanical properties of concrete. The tested properties include; compressive strength, tensile strength, flexural strength, fineness modulus, specific gravity, moisture content, water absorption, bulk density, and porosity.

2.1. Materials

Ordinary Portland Cement in accordance to ASTM Type I was used throughout the work for mixing concrete complying with specifications in ASTM Standard C150 [61]. Table 1 demonstrates the physical properties of cement. Sand passing through 5.00 mm sieve was used as fine aggregates with specific gravity of 2.67. Machine crushed limestone passing through 20 mm sieve and retained on 4.75 mm sieve were used as coarse aggregates with specific gravity of 2.7. The sawdust was immersed in solution of NaOH with concentration 5 % for two hours to lose some amount of lignin. Then washed several times using fresh water before being oven dried for one night at 100 °C. Sawdust used as fine aggregate was composed of particles that passed through 5.00 mm sieve. While saw dust used as replacement of cement was sieved through sieve 200 after being burned at temperature of 200 °C. Chemical composition of sawdust is given in Table 2. Physical properties of fine and coarse aggregate are demonstrated in Table 3. Sieve analysis for sawdust, prepared in accordance of ASTM C136/C136M-19 [62], is illustrated in Table 4.

2.2. Concrete mix design

Thirteen concrete mixtures were prepared where sawdust was used to replace either sand or cement at percentages of 0 %, 5 %, 10 %, 15 %, 20 %, 25 %, and 30 %. The proportional ratio of cement: fine aggregate: coarse aggregate was 1:1.5:3 and design was proposed by using ACI 211.1 [63]. The water to cement ratio was set to 0.45 to obtain concrete with grade M-25. The mixture proportions are shown in Table 5. In order to validate that all sawdust concrete mixes attain the required workability, the slump test was performed, the slump test results ranged from 133 mm to 170 mm. Mixtures were then cast in standard moulds required for each test. The concrete mixtures were poured into the mould in three layers followed with compaction in between those layers to assure well compaction, thus avoiding any deficiencies such as honeycombs and air traps. A total 234 specimens were casted. After 24 hours of casting, the specimens were demoulded and moist cured till the day of testing in accordance to ASTM C192 [64].

Table 1. Physical properties of cement.

Characteristics	Value
Specific gravity	3.12
Initial setting time(min.)	28
Final Setting time(min.)	615
Standard consistency	37

Table 2. Chemical composition of sawdust.

Oxides	Percentages
SiO_2	68.5
Al_2O_3	5
Fe_2O_3	3.3
CaO	10.5
MgO	6.7
MnO	0.01
Na_2O	0.07
K_2O	0.1
P_2O_5	0.44
SO_2	0.47

Table 3. Physical Characteristics of sawdust, sand, and coarse aggregate.

Characteristics	Sand	Sawdust	Coarse aggregate
Specific gravity	2.67	2.5	2.7
Fineness	2.31	1.78	----
Moisture content %	3.7	0	0
Bulk density(kg/m^3)	1570	1250	1450
Voids %	41	64	39
Water absorption %	0.47	0.58	8

2.3. Tests on hardened concrete

The effect of replacement of fine aggregate and cement with sawdust with different percentage was assessed by determining specific gravity, water absorption, moisture content, bulk density, compressive, flexural strength, and tensile strength.

2.3.1 Water absorption test

The specimens required for water absorption test were demoulded and immersed in water for 24 hours before being tested according to ASTM C642[65].

2.3.2 Compressive strength test

Six cubes of size 150 mm × 150 mm × 150 mm, uncertainty of reading dimensions = ± 0.05 mm, were prepared from each concrete mixture for investigation of compressive strength. The concrete specimens were cured under normal conditions as per ASTM 192 [64] and were tested using Universal Test Machine at 28 and 90 days. The test method requires rounding to nearest 0.1 N/mm, expanded uncertainty at level of confidence = 1.21 N/mm^2.

Table 4. Sieve analysis for sawdust and sawdust ash.

Sieve size	% passing of saw dust	% of passing for saw dust ash
Sieve 4	95	100
Sieve 8	89	100
Sieve 16	77	100
Sieve 30	49	100
Sieve 50	18	97
Sieve 100	1.25	92
Sieve 200	0.10	90

Table 5. Proposed mix proportion and slump test results.

Mix No.	% of replacement	Cement	Water	F. Aggregate	C. Aggregate	Sawdust	Slump
FC	0	450	202.5	675	1350	0	150
F1	5	450	202.5	641.25	1350	33.75	142
F2	10	450	202.5	607.5	1350	67.5	141
F3	15	450	202.5	573.75	1350	101.25	140
F4	20	450	202.5	540	1350	135	140
F5	25	450	202.5	506.25	1350	168.75	137
F6	30	450	202.5	472.5	1350	202.5	133
C1	5	427.5	202.5	675	1350	22.5	158
C2	10	405	202.5	675	1350	45	160
C3	15	382.5	202.5	675	1350	67.5	163
C4	20	360	202.5	675	1350	90	167
C4	25	337.5	202.5	675	1350	112.5	168
C6	30	315	202.5	675	1350	135	170

2.3.3 Tensile test

150 × 300 mm cylinder specimens were used to detect the tensile strength. Seventy-eight specimens were cast and cured in water at room temperature in the laboratory for 7 and 28 days. After curing, three specimens for each mixture were tested for tensile strength in accordance to ASTM C496/C496M-17 [66] and the average was recorded.

2.3.4 Flexural Strength

Flexural strength was measured using 100 × 100 × 500 mm beam specimen in the centre of the beam load applied. A total of 78 beams were cast and cured in water for 28 and 90 days. For each mixture, three beams were loaded to failure in accordance to ASTM C78/C78M-18 [67], and the average strength was recorded in each case.

3. Results and Discussion

3.1. Density

The density of concrete dimensioned with the increase in sawdust content. Fig. 1 illustrates the average density of concrete specimens. The density at 28 days for mix with 30 % replacement of sand and cement was less than that of the control mix by 7 % and 5 % respectively. The density of sand and cement is higher than the density of sawdust, therefore a decrease in density is associated with mixtures with sawdust. The range of densities was 2100–2400 kg/m^3 for all the replacement values. This revealed that the concrete with sawdust can be considered as normal weight concrete. This is in agreement with results of Layla and Hasan [13] and Mageswari and Vidivelli [14] who suggested that the decrease in density of sawdust concrete is about 4–5 %. However, Abdulet et al [19] postulated that the decrease in density can reach 40 % using mixtures with ratio 1:3 cement to sawdust.

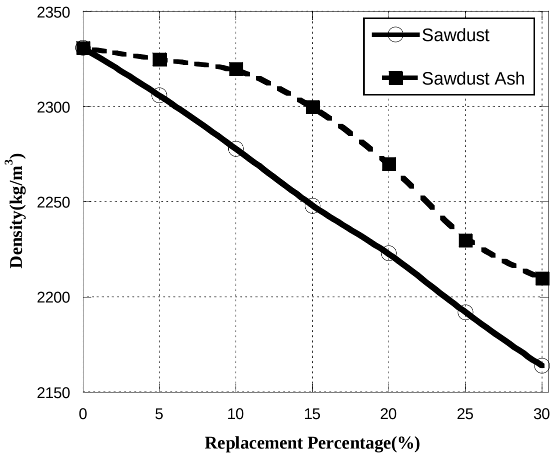


Figure 1. Effect of replacement of sand and cement on density of concrete.

3.2. Water absorption

Water absorption for specimens from different mixtures was calculated. It was deduced that water absorption enlarged with rising content of saw dust. The range of increase in water absorption was from 13 % to 80 higher than that of control mix with the maximum rate of water absorption for concrete mix with 30 % saw dust content, however it is still in the accepted limits. Table 6 represents the percentage of water absorption for different mixtures tested.

Table 6. Percentage of water absorption.

Mix No.	Dry weight of cube(gm)	Wet weight of cube (gm)	Water absorbed	% of water absorption
FC	8360	8460	100	1.19 %
F1	8450	8564	114	1.35 %
F2	8235	8360	125	1.52 %
F3	8225	8361	136	1.65 %
F4	8000	8147	147	1.84 %
F5	7900	8059	159	2.00 %
F6	7880	8052	172	2.18 %
C1	8462	8566	104	1.22 %
C2	8335	8450	115	1.38 %
C3	8225	8351	126	1.53 %
C4	8000	8137	137	1.71 %
C4	7990	8140	150	1.88 %
C6	7970	8132	162	2.03 %

3.3. Compressive strength

The effect of incorporation of sawdust on compressive strength of concrete, as given in literature, was contradicting. Researchers [50] suggested that 30 % replacement of fine aggregate with sawdust increased the compressive strength by 13 %. On the other hand, Layla and Hasan [48] argued that the 25 % of sawdust decreases the compressive strength by 54 %. The results of this work indicated that on testing the effect of replacement of natural sand with sawdust on the compressive strength, it was perceived that the compressive strength was not affected at 5 % replacement. The 10 % sawdust replacement attained the highest compressive strength with nearly 3 % more than that of control mix. At percentage higher than 10 %, the compressive strength decreased with the increase in the percentage of sawdust. However, all specimens surpassed the designed value of concrete grade 25. Accordingly, this certainly ensure that the designed sawdust mix can be effectively used to obtain the required strength. The results are shown in Fig. 2(a). As for the results of partial replacement of cement with sawdust ash, the compressive strength decreased with increasing percentage of replacement. The highest rate of reduction was 10.3 %, see Fig. 2(b). However, the replacement of cement with sawdust ash by percentage up to 15 % decreased the compressive strength by only 5 %. These results confirmed that with proper concrete mix proportion the sawdust can be effectively used as partial replacement of fine aggregate and cement.

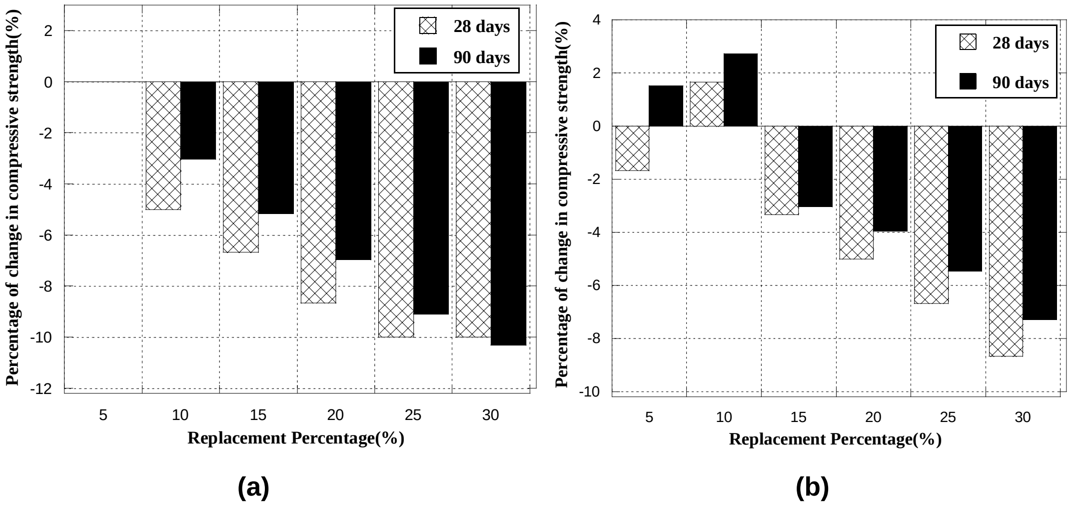


Figure 2. Compressive strength for mixes (a) sawdust replacing sand, (b) sawdust ash replacing cement.

3.4. Tensile Strength

The results at 28 days showed that the replacement of natural sand and cement with sawdust and sawdust ash decreases the tensile strength despite the percent of replacement compared to the control mix. However, at 90 days the results implied that incorporation of sawdust with percentage up to 15 % improves the tensile strength. The extreme degree of enhancement in case of replacing of natural sand was 10 % while in case of replacing cement was 4 %. This is in agreement with previous results in literature [49–50]. Fig. 3 demonstrates the tensile strength for specimens with sawdust and sawdust ash.

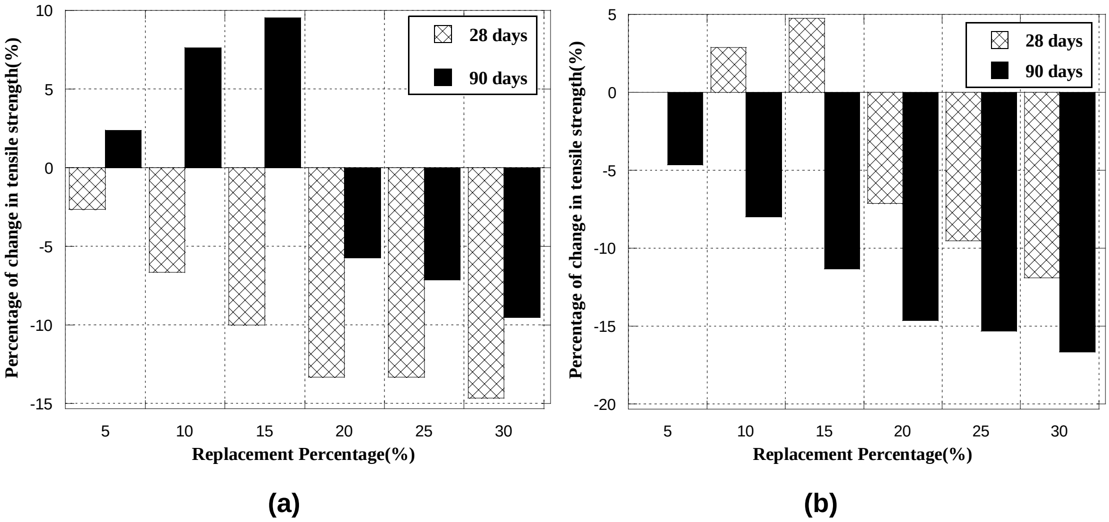
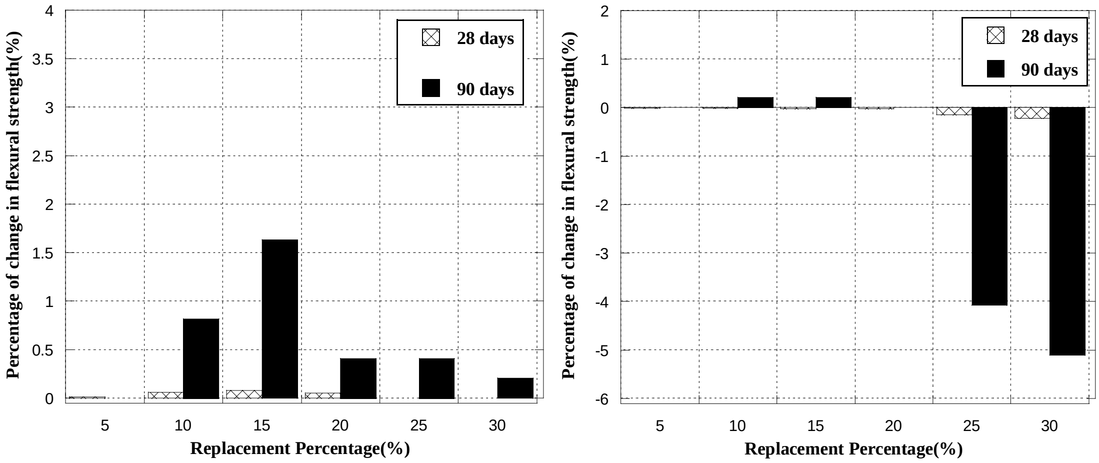


Figure 3. Tensile strength for mixes (a) sawdust replacing sand, (b) sawdust ash replacing cement.

3.5. Flexural Strength

The substitution of natural sand with sawdust has nearly no effect on the flexural tensile strength, the results indicated comparable values to control specimens at all considered levels of replacement. This may be attributed to the fact that the saw dust used served as a source of strengthening in the beam specimens, the results for 28-day and 90 days are shown in Fig. 4. As for substituting cement with sawdust ash, the results signified that up to 20 % of replacements, the sawdust has nearly no effect on the flexural strength. However, beyond 20 % the increase in percentage of replacement decreases the flexural strength. The maximum reduction was 5 % at 30 % of replacement, see Fig. 7. This is in accordance with results obtained by previous researchers [49, 54, 59]. Conversely, Chitra et al [50] overemphasized that 30 % sawdust increased the flexural strength by 8 %.



(a) **(b)**

Figure 4. Flexural strength for mixes (a) sawdust replacing sand, (b) sawdust ash replacing cement.

4. Conclusions

Sawdust is a leftover material comes from cutting or sawing of wood. It is available in ample amounts, and it is suitable for use in concrete production. This will go a long way to reduce the quantity of waste in our environment. The fineness modulus, specific gravity, moisture content, uncompacted bulk density and compacted bulk density of concrete with Sawdust ash were found to be 2.2, 2.67, 3.7 %, 1435 kg/m^3 and 1436 kg/m^3. For a certain mix, the water requirement increases as the SDA content increases. The compressive strength, tensile strength, and flexural strength for all mix increases with age of curing. The optimum replacement level in fine aggregate with SDA is 15 %.

Depending on results of the experimental study the succeeding points were concluded:

- The replacement of sand and cement with sawdust decreases the density of the concrete.
- The replacement of sand and cement with sawdust has opposed effect on workability.
- For a constant mix proportion, the water absorption increases as the sawdust content increases.
- The compressive strength, tensile strength, and flexural strength of the concrete for different mix increases with age of curing.
- The compressive strength of the concrete with 10 % substitution of natural sand increases the compressive strength.
- On testing the flexural strength, the replacement of sand with sawdust improves the strength while the replacement of cement with sawdust ash has negligible effect.
- The optimum replacement percent with sawdust is 15 %.
- Use of sawdust ash and sawdust in concrete has positive effect on economic and environment.

From the above review, the potentials for wood waste to be used as structural concrete constituent for the development of sustainable built environment is not in disbelieve. However, more works need to be done, either to approve some perceived behaviour, or cover to areas that are not yet studied as: bending behaviour, stiffness, shear behaviour, and bond characteristics. These are thus recommended for further investigations.

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