

Statistical Evaluation of the Effect of Organic Admixture on the Mechanical Properties of Wood Shavings-Concrete for Building Construction

Akpokodje OI^{1*}, Agbi GG², Uguru H³

¹Department of Civil Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria

²Department of Civil Engineering, Delta State University, Oleh Campus, Nigeria

³Department of Agricultural and Bio-Environmental Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria

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*Corresponding author: Akpokodje OI

Abstract

The quest for green concrete is on the rise globally, due to the environmental hazards (emission of CO₂ and particulate matters) usually associated with cement and coarse aggregate production. This study was carried to evaluate the possibility of enhancing the mechanical properties of wood shavings-concrete with cassava starch solution. Sets of concrete were produced with wood shavings at the rate of 1%, 1.5%, 2%, 2.5%, 3%, 3.5% and 4% (by weight of the coarse aggregate). 2% (by weight of the cement) dried cassava starch was employed as organic admixture during the concrete production. Conventional mix ratio of 1:2:4, and water to cement ratio (w/c) of 0.6 was also adopted for the concrete production. The slump of the fresh mortar, and the density, compressive and flexural strengths of the hardened concrete were tested in accordance to ASTM International procedures. Results obtained from the laboratory tests revealed that the wood shavings had negative impact on the mechanical properties of the concrete. The compressive and flexural strengths of the concrete decreased, as the quantity of the wood shavings increased from 0% to 4%. When compared to the results obtained from concrete produced without cassava starch, it was observed the cassava starch enhanced the compressive and flexural strengths of the concrete produced. Regression analysis of the obtained results affirmed that wood shavings and cassava starch can influenced the mechanical properties of concrete, as concrete produced with cassava starch had higher a Pearson correlation coefficient, than the concrete produced without cassava starch. Results obtained from this study showed the feasibility of producing lightweight green concrete, by using low volume of wood shavings and cassava starch as admixture.

Keywords: Cassava starch, green concrete, mechanical properties, organic admixture, wood shavings.

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INTRODUCTION

Concrete production consumes a lot of natural resources, and contributes chiefly to climate change; tons of carbon (iv) oxide (CO₂) is emitted into the environment during Portland cement production, and cement is one of the main constituent of conventional Portland cement concrete. It had been recorded that about 5% of the greenhouse gas is emitted during the process of cement production (Hendriks *et al.*, 2000; Akpokodje *et al.*, 2019). The utilization of concrete in residential building construction has increased drastically in the last decade (mostly in Africa countries due to explosive population growth); resulting from the need to provide accommodation for the growing human population in the world. According to Alengaram *et al.* (2011), concrete are widely employed in building construction due to its flexibility and relative high compressive strength.

Apart from cement that consumes a lot of energy and emits greenhouse gas (CO₂) during its production; gravel (coarse aggregate), is another major constituent of concrete that consumes reasonable amounts of energy and emits a lot of particulate matter/gasses into the environment, during its production. Mukherjee and Vesmawala (2013) reported that building construction consumes about 32% of the total energy consumed globally, and this consumption generates about 20% of the greenhouse gas emissions. According to Langer (2001) a lot of particulate matter is produced during the blasting, crushing and screening of the rocks, into small size coarse aggregates. Howard and Cameron (1998) reported that, the prevailing winds, ambient air quality and the rock physic-mechanical properties are some of the vital factors that affect the deposition rate of particulate matters within stone quarrying sites. During rocks blasting, some of the

energy escapes into the atmosphere, causing disturbance in the air (air concussion), which lead to vibrations of structures within the vicinity of such sites. Furthermore, in poorly controlled blasts, flyrock are produced, which is a major environmental threat to lives and properties within the area (Langer, 2002).

To curb the threat of from convectional materials in concrete production, research on organic materials is developing safer and more sustainable materials for the building industry. According to Umurhurhu and Uguru (2019), organic (green) materials are environmental friendly, light weight and have good mechanical properties; although some of them are susceptible to fungi and insects attack. Green concrete production involved replacing one or all the major concrete constituents (cement, fine aggregate and coarse aggregate) with organic or recycled material(s). The resultant green concrete produced should have fairly appreciable mechanical properties and life-cycle sustainability (Al-Mansour *et al.*, 2019). Lau *et al.* (2018) stated that apart from the utilization of organic or recycled materials in green concrete production, nano size particles can also be used to enhance the sustainability of green concrete. For instance carbon nanotube (CNT) is now being used in the production of concrete (Yu and Lau, 2017). However, poor compressive strength in concrete produced with high volume of organic materials is attributed to poor bonding caused by poor quantity/weak interfacial adhesion between the substitute material(s) and tobermorite gel produced by the cement (Oghenerukewve and Uguru, 2018; Akpokodje *et al.*, 2021).

Lightweight concrete usually employ lightweight materials as substitution for the conventional materials. Some of these lightweight materials include wood chippings (wood shavings, sawdust, etc.), which are waste materials obtained from timber industries (Sotiropoulou *et al.*, 2017). Although several experimental studies (Coatanlem *et al.*, 2006; Sales *et al.*, 2011; Sotiropoulou *et al.*, 2017) have been carried out on the feasibility of using wood chippings in concrete production, for residential or commercial buildings; no literature had been recorded on the utilization of organic admixture in the production of wood shavings reinforced concrete. Therefore, this study was carried out to evaluate the possibility of using cassava starch in solution, to enhance the mechanical properties of wood shavings reinforced concrete, for the production of light-weight concrete for building construction.

MATERIALS AND METHODS

Water

The borehole water used for the concrete production was free from toxic contaminants, suspended solids, etc., and has a pH value of 7.2 and an electrical conductivity of 45 $\mu\text{S}/\text{cm}$.

Cement

Ordinary Portland Cement (OPC) of the Dangote brand, with standard cement grade strength of 42.5 N/mm², was used for the concrete production. Grade 42.5 cement produces concrete with higher compressive strength than grade 32.5 cement (NIS 444-1, 2003; Akpokodje *et al.*, 2020).

Fine aggregate (sand)

Natural riverbed sand (sharp sand) from Ase River in Delta State, Nigeria was used for the concrete production. To reduce the moisture content to appreciable level, the sand was air dried under ambient temperature condition in the concrete laboratory for one week. The moisture content of the sand can be altered the water-cement ratio, which will ultimately affect the mechanical properties of the concrete produced (FAO, 2011).

Coarse aggregate

Granite crushed into 20 mm gauge size was used for the concrete production. To reduce the aggregate moisture content to appreciable level, the coarse aggregate was also air dried under ambient temperature in the laboratory for one week.

Wood shavings

The wood shavings were obtained from a hardwood timber. They were dried to appreciable moisture content in the laboratory for one week.

Cassava starch

Dried cassava starch was used as an organic enhancer in the concrete production. A constant cassava starch quantity at the ratio of 1% (by weight of the cement), was adopted through the concrete production process, irrespective of the volume of wood shavings introduced. The cassava starch was dissolved in the water to be used for the concrete production.

Preliminary Tests

Particles size graduation

The British Standard (BS) was employed in determining the particles size graduation for both the fine and coarse aggregates used in the concrete production.

Specific gravity determination

The specific gravity of the sharp sand was measured in accordance to ASTM D854 – 14 (2004) procedures, and calculated by using the expression presented in Equation 1. The specific gravity of the sharp sand was found to be 2.59.

$$S_g = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \quad 1$$

Where:

W_1 = Weight of the empty bottle
 W_2 = Weight of the bottle filled fine aggregates.
 W_3 = Weight of the bottle and its content filled with distilled water up to the meniscus.
 W_4 = Weight of the bottle filled with distilled water to the meniscus (Agbi *et al.*, 2020).

Mix ratio

A mix of 1:2:4 (C15) (Batching by volume) was used for the concrete production. Furthermore, a fairly high water-cement ratio of 0.6 was used for the concrete production. This fairly high (0.6) water-cement ratio was taken, because preliminary laboratory investigation revealed that the workability of fresh concrete (slump) produced with a lower water-cement ratio (<0.6) was very harsh (0.0 mm), which can be attributed to the high water absorption rate of the dried wood shavings. Likewise, the authors declined to adopt the procedures adopted by some researchers (Mohammed *et al.*, 2014; Corinaldesi *et al.*, 2016), that soaked the wood shavings in water in order to saturate them. This is because, the actual value of the water-cement ratio under such conditions may not be adequately ascertained, as the volume of water that will seeped or be discharged from the wood shavings into the concrete may not be adequately evaluated.

Production of concrete cubes

During the concrete cube production, the fresh mortar was filled into a standard mould (150 mm x 150 mm x 150 mm) in three equal layers. Each layer was rammed thirty five times, and the top of the mortar flatten (leveled) with a hand trowel. The concrete cubes were then covered with a black polyethylene sheet and left under a shady environment for twenty four hours, before they were removed from their moulds and cured with fresh borehole water by total immersion method.

Concrete beam production

During the concrete beam production, the fresh mortar was filled into a standard mould (500 mm x 100 mm x 100 mm) in three equal layers. Each layer was rammed thirty five times, and the top of the mortar flatten (leveled) with a hand trowel. The concrete beam were then covered with a black polyethylene sheet and left under a shady environment for twenty four hours, before they were demoulded and cured with fresh borehole water by total immersion.



Fig-1: Covering of the concrete cubes and beams produced

Laboratory test

Test on fresh concrete

Slump test for the fresh concrete was performed in accordance with ASTM C143 (2020) recommended procedure; to determine the consistency and workability of the concrete.



Fig-2: The slump test

Density determination

The density of the concrete was determined by Gravimetric method, in accordance with ASTM C138 (2017) procedures, and calculated with the expression shown in Equation 2.

$$\text{Density } (\rho) = \frac{M}{V} \quad 2$$

Where:

M = Mass of the concrete

V = Volume of the concrete (Akpokodje *et al.*, 2020).

Compressive strength determination

The compressive strength of the concrete cubes produced was determined in accordance with ASTM C109/C109M (2020) recommended procedures, by using the concrete Compression Testing Machine (Model: STYE 2000). During the test, the concrete cube was placed in between the two platens of the machine and loaded axially, until failure of the concrete cube was attained. Then the compressive strength of the concrete cube was calculated by using the expression shown in Equation 3 (Akpokodje *et al.*, 2020).

$$\text{Compress strength} = \frac{F}{A} \quad 3$$

Where:

F = Crushing force (N)

A = Net area of concrete cube (mm²)

Flexural strength determination

The flexural strength of the concrete beam was determined in accordance with ASTM C78 / C78M - 21 (2021) recommended procedure, using the Third-Point Loading method. During the test, each beam was placed within the three-point loading apparatus, and loaded slowly until failure of the concrete beam occurred approximately at the midspan. The corresponding failure force, displayed on the screen of the machine was recorded, and the flexural strength of the concrete beam was computed using equation 4 (Akpokodje *et al.*, 2019).

$$\text{Flexural strength } (S) = \frac{3WL}{2bd^2} \quad 4$$

Where:

W = Maximum load indicated by the testing machine (N),

L = Concrete beam Span (mm),

b = Average width of the concrete beam at the plane of failure (mm),

d = Average depth of the concrete beam at the plane of failure (mm).

STATISTICAL ANALYSIS

Results obtained from the study were subjected to regression analysis to evaluate the impact of the wood shavings and cassava starch on the mechanical properties of the concrete produced.

RESULTS AND DISCUSSION

Physical characteristics

Figure 3 revealed that the fine aggregate used for the concrete production contained 2.4 fines and had a conformity coefficient "Cu" of 6.3. As revealed by the results of the particle grading plotted in Figure 3, the fine aggregate was well graded, satisfying the ASTM D2487-11 requirements. The ASTM D2487-11 recommended that fine aggregate considered suitable for concrete production should have uniformity

coefficient (Cu) greater than 6 (Cu >6), and fines particles less than 5% (ASTM D2487, 2011; USCS, 2015).

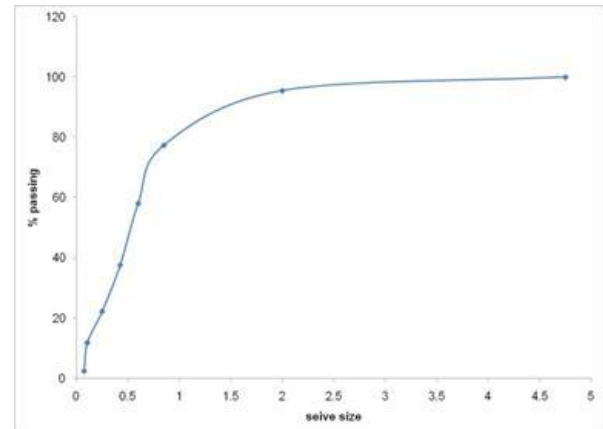


Fig-3: The particle size distribution curve

Cu = 6.3; Fines = 2.4

Slump of the fresh mortar

The results of the slump test are given in Table 1. As shown in the results, regardless of the cassava starch admixture in the fresh concrete, the slump decreased monotonically as the wood shavings increased from 0 kg to 4 kg. It was observed from the results that the fresh concrete produced with cassava starch had higher slump values, compared to that of fresh concrete produced without cassava starch, for same quantity of wood shavings added. At 0% (0 kg) of wood shavings per volume of coarse aggregate, a slump of 23.2 mm was recorded in the concrete produced without cassava starch; while a slump of 28.4 mm was recorded in the concrete produced with cassava starch. Likewise, at 3 kg (3% volume of coarse aggregate) wood shavings volume, the concrete produced without cassava starch recorded a 0.0 mm slump, while the concrete produced with cassava starch recorded a 0.9 mm slump. This portrayed that cassava starch acts as an organic workability enhancer, by increasing the workability of the fresh mortar.

The lower workability of the fresh concrete as the wood shavings increases is attributed to a higher water absorption rate, consequently lowering the water volume available for lubrication; and ultimately for the hydration of the cement in the fresh mortar. Water volume is one of the key factors that influence the workability of fresh concrete; hence its shortage leads to production of concrete with harsh (poor) workability. According to Mohammed *et al.* (2014), wood shaving has sponge characteristics; therefore it has the ability of either absorbing water or releasing water to its surrounding, depending on the moisture status between it and its surrounding. Similarly results were obtained by Sotiropoulou *et al.* (2017) where the workability fresh mortar decreases as the volume of the wood shaving increased from 30% to 70%.

Table-1: The slump and density of the concrete produced

Wood shavings (kg)	Slump (mm)		Density (kg/m ³) at day 28	
	No starch	Starch	No starch	Starch
0	23.2	28.4	2518±35	2609±43
1	12.5	15.8	2496±44	2545±39
1.5	5.2	10.5	2335±22	2478±22
2	2.8	5.9	2284±21	2391±25
2.5	0.4	2.1	2192±19	2307±33
3	0	0.9	2103±24	2281±25
3.5	0	0	2062±20	2194±21
4	0	0	1985±15	2073±20

± Standard deviation

Concrete density

The concrete density results are presented in Table 1. As shown by the results, the concrete density decreased with increase in the quantity of wood shavings, for both the “starch and “no starch” cases. It was observed that the control concrete with cassava starch had the highest density (2609 kg/m³), which was closely followed by the concrete produced without cassava starch admixture (2518 kg/m³). Density values declined non-linearly to 1985 kg/m³ (4% wood shavings) for the concrete produced with wood shaving

and without starch admixture, and 2073 kg/m³ (4% wood shavings), for the concrete produced with wood shaving and with starch admixture respectively. This portrayed that wood shavings and cassava starch played significant roles in the concrete weights.

Statistical analysis of the concrete’s density (ρ) as a function of the quantity of wood shavings (Ws), was evaluated by the following regressions given in Equations 5 and 6.

For concrete produced without starch admixture

$$\rho = -144.9 Ws + 2564$$

$$R^2 = 0.966$$

$$(r = -0.9831)$$

5

For concrete produced starch admixture

$$\rho = -133.9 Ws + 2652.$$

$$R^2 = 0.972$$

$$(r = -0.9860)$$

6

Where:

ρ is the density (unit weight) (Kg/m³)

R^2 is the coefficient of determination,

r is the Pearson correlation coefficient.

The Pearson correlation coefficient values (Pearson “ r ” = -0.9831 for concrete produced without starch admixture and Pearson “ r ” = -0.9860 for concrete with starch admixture) further affirmed the strong relationship, between the volume of wood shavings to the density of the concrete produced. These results are in similar trend to those previously reported by Boob (2014), where the density of sandcrete blocks incorporated with sawdust declined from 2400 Kg/m³ to 1800 Kg/m³, as the sawdust volume increased from 0% to 20%. Similarly, Mohammed *et al.* (2014) reported that the density of concrete blocks decreased from 1915.43 Kg/m³ to 1554.15 Kg/m³ as the wood shavings increased from 0% to 30%.

Compressive strength

The results of the compressive strength of the concrete cubes are presented in Figure 4. As seen in the results, the compressive strength of concrete containing wood shavings decreased as the quantity of wood shavings increased, regardless of the presence of cassava starch introduced. This generally signified that quantity of cement, fine and coarse aggregates in the

concrete mixture impacted positively on the compressive strength of the concrete produced. The findings of this study showed a significant statistical relation between wood shavings fraction and the compressive strength of the concrete (Pearson $r = -0.9905$ for concrete without starch admixture and Pearson $r = -0.9976$ for concrete with starch admixture). Osei and Jackson (2016) and Sotiropoulou *et al.* (2017) reported similar observations, in which the compressive strength of concrete produced with wood chippings decreased continually with increase in the quantity of wood chippings. Vaidkelionis and Vaickelionene (2006) stated that wood particulates helped to retard the cement hydration, through the absorption some water from the fresh mortar; hence, decreasing the compressive strength of the concrete during aging. But the compressive properties of the concrete produced with wood particulates, can be enhanced through the incorporation of appropriate admixture into the concrete.

Additionally, the results portrayed that, the concrete produced with cassava starch admixture developed higher compressive strength at curing day 28, regardless of the quantity of wood shavings considered. This showed that cassava starch helped the strength development in concrete during aging. Similar findings were previously reported by Abalaka (2011),

Okafor (2008) and Akpokodje *et al.* (2020), where concrete produced with cassava starch had higher compressive strength during aging, compared to the concrete produced without cassava starch.

As revealed by the results (Figure 4), wood shavings can generally be used as admixture in concrete production. Addition of 2% (by weight of coarse aggregate) of wood shavings as admixture in concrete production, will produce concrete that will meet the minimum compressive strength (17 MPa), required for concrete to be utilized for residential buildings, provided that adequate admixture(s) are added to the concrete. Likewise, if suitable admixture(s) are not utilized during the process of the concrete production, incorporating 1% (by weight of coarse aggregate) of wood shavings into the fresh concrete produces lightweight concrete with appreciable compressive strength, that can be used in residential structures.

The regression analysis of the concrete Compressive strength (Cs) as a function of the quantity of wood shavings (Ws), with and without cassava starch are represented by the regression equations, given in

Concrete produced without starch admixture
 $Cs = -5.535 Ws + 27.58$ $R^2 = 0.981$

($r = -0.9906$) 7

Concrete produced starch admixture
 $Cs = -5.957 Ws + 31.12$ $R^2 = 0.995$

($r = -0.9976$) 8

Where:
 R^2 is the coefficient of coefficient of determination,
 r is the Pearson correlation coefficient.

Flexural Strength

The results of the flexural strength of the concrete beams are presented in Figure 5. As portrayed by the results, at curing day 28, the flexural strength of the concrete generally decreased with increase in the volume of wood shavings, regardless of the presence of starch admixture. The flexural strength of the concrete declined from 7.71 MPa to 3.99 MPa, in the concrete produced without cassava starch, as the wood shavings increased from 0 kg to 4 kg. Likewise, the flexural strength of the concrete treated with cassava starch declined from 8.54 MPa to 4.75 MPa, as the quantity of wood shavings increased from 0 kg to 4 kg. This revealed that the cassava starch enhances the flexural strength of the concrete produced with it, irrespective of the decline in strength. The statistical relationship of the concrete flexural strength (Fs) as a function of quantity of wood shavings (Ws) was evaluated by means of regression Equations 9 and 10.

The results further revealed a significant statistical relationship (Pearson $r = -0.9546$ for concrete

Equations 7 and 8. The high Pearson correlation coefficient ($r \geq \pm 0.95$) values portrayed that there is a strong relationship between the quantity of wood shavings and the compressive strength development in the concrete.

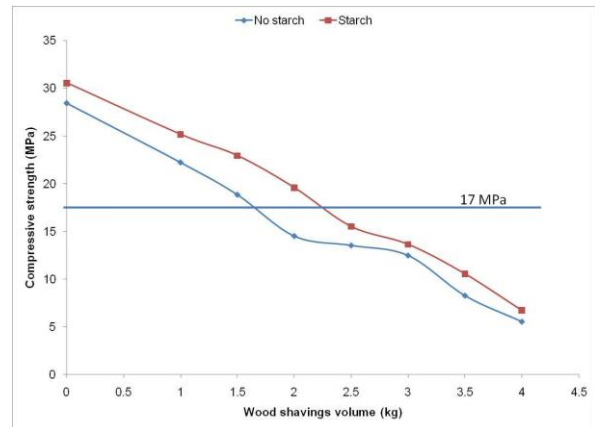


Fig-4: Relationship between compressive strength and quantity of wood shavings

without starch admixture and Pearson $r = -0.9811$ for concrete with starch admixture) between the wood shavings quantity and the flexural strength of the concrete produced. Similar results were reported by Sotiropoulou *et al.* (2017), where a strong correlation existed between the flexural strength of concrete produced and the quantity of wood materials incorporated into the concrete.

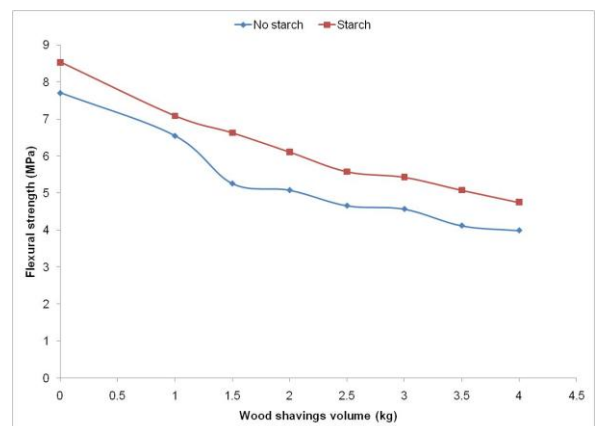


Fig-5: Relationship between compressive strength and quantity of wood shavings

Concrete produced without starch admixture;
 $F_s = 0.198 W_s^2 - 1.724 W_s + 7.754$ $R^2 = 0.975$ $(r = -0.9546)$ 9

Concrete produced starch admixture;
 $F_s = 0.140 W_s^2 - 1.483 W_s + 8.507$ $R^2 = 0.996$ $(r = -0.9811)$ 10

Correlation between compressive strength with concrete density

The statistical relationship between the concrete compressive strength and its density, with respect to the quantity of wood shavings incorporated into the concrete was further buttressed by correlation evaluations. The correlation curve and co-efficient presented in Figures 6 and 7; and equations 11 and 12,

Concrete produced without starch admixture;
 $C_s = 1E-052 \rho^2 - 0.023 \rho + 0.568$ $R^2 = 0.936$ $(r = 0.9664)$ 11

Concrete produced with starch admixture;
 $C_s = 2E-05 \rho^2 - 0.064 \rho + 41.63$ $R^2 = 0.993$ $(r = 0.9931)$ 12

As presented in Table 1, the density of the concrete was greatly influenced by the quantity of the wood shavings incorporated into the concrete; hence the high Pearson correlation coefficient values ($r \geq 0.90$) recorded in Equations 11 and 12. This further affirmed the earlier accretion that high quantity wood shavings in the concrete, will lead to poor compressive strength development in concretes. Furthermore, as displayed by Figures 5 and 6, and represented by the correlations values in equations 11 and 12, the concrete produced with cassava starch had a better compressive strength and density relationship, than that of its counterpart produced without cassava starch admixture.

revealed that there is a strong relationship between the density of the concrete and its compressive strength.

The best fit lines representing the regression relationship between the concrete compressive strength versus density at day28, for both the concretes produced with, and that produced without cassava starch, are given as:

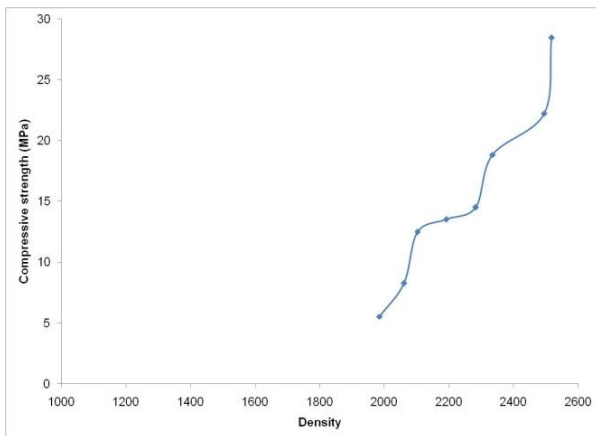


Fig-6: Compressive strength versus density for concrete produced without cassava starch

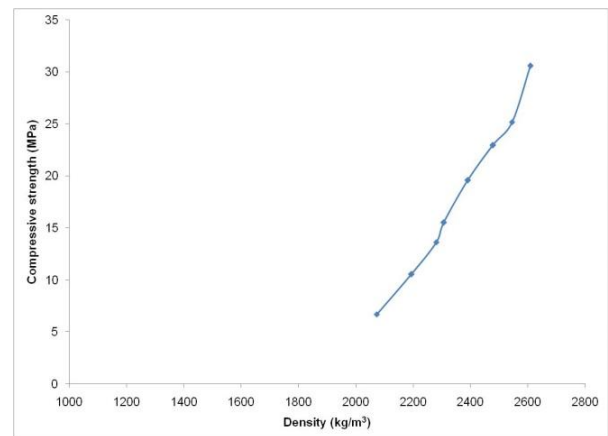


Fig-7: Compressive strength versus density for concrete produced with cassava starch

CONCLUSION

From the experimental results, the following conclusions can be drawn:

- i. The density of the concrete decreased as the quantity of wood shavings incorporated into the concrete increased from 0% to 4% (weight of the coarse aggregate).
- ii. The compressive and flexural strength of the concrete decreases monotonically as the quantity of wood shavings incorporated into the concrete's increased.
- iii. The workability of the fresh concrete decreases as the quantity of wood shavings increases.
- iv. Addition of cassava starch into concrete improves its workability, as well as its compressive and flexural strengths.
- v. Low volume of wood shavings (about 1.5% of the coarse aggregate weight) can be used for concrete production in residential buildings.

- vi. Higher quantity of wood shavings (about 2% of the coarse aggregate weight) can be used for the production of light weight concrete wall panels in residential buildings, provided adequate admixture(s) are utilized.

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