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RESEARCH ARTICLE

# Experimental Investigation of the Physical and Mechanical Properties of Cassava Starch Modified Concrete

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**Abstract:**

***Background:***

Concrete is a widely used material in construction, which has given rise to innovations in terms of modifying some of its properties to meet desired requirements. The use of chemical admixtures is important in this regard, which has necessitated the search for new materials that can serve as a substitute.

***Objective:***

This research work investigates the use of Cassava Starch (CS) as an admixture for improving the physical and mechanical properties of concrete.

***Methodology:***

The physical and mechanical properties of concrete were studied by adding CS by weight of cement at 0.4, 0.8, 1.2, 1.6 and 2.0%, respectively. Concrete cubes and cylinders were cast and cured for a test period of 7, 14, 28, 56 and 90 days, respectively. Unreinforced beams of size 150 x 150 x 530 were cast and cured for 28 days. A total of 6 mix proportion was used, five out of which were used to examine the effect of CS on the properties of concrete.

***Results:***

The workability of concrete was reduced as the percentage of CS increased due to its viscosity modifying properties. CS increased the initial and final setting time of concrete for every increase in percentage addition. An improvement in the compressive strength, split tensile strength, flexural strength and elastic modulus of concrete were noticed for cassava starch-modified concrete over the control for some of the mixes at all days of curing. The density of concrete was found to decrease at 1.6 and 2.0% addition of CS in concrete.

***Conclusion:***

From the results of this investigation, CS improved the compressive, split tensile, flexural and elastic modulus of concrete at an optimum of 0.8 percentage addition of CS. The setting time of concrete was also increased, which makes CS suitable to be used as a retarding admixture in hot weather concreting. Based on the findings of the work, CS can be considered as an admixture to be used as a substitute for retarders and viscosity modifying admixtures for improved concrete properties.

**Keywords:** Cassava starch, Setting time, Workability, Compressive strength, Split tensile strength, Flexural strength, Density, Static modulus of elasticity.

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|---|---|---|---|

## 1. INTRODUCTION

Concrete is an important material used in construction because of its desirable properties, such as its compressive strength. Concrete is a composite material consisting of three components: the cement matrix, the aggregate and the interface between the matrix and aggregate [1]. Admixtures are sometimes added to modify the engineering properties of the resulting composite such as strength, workability and time of hardening [2]. Due to engineering requirements for concrete structures to perform in the advent of challenging environmental factors, it is necessary to have new and innovative concrete technologies which will perform satisfactorily under

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different loading conditions. It has been concluded that the capability to control the rheology of concrete could be considered a catalyst for many of today's concrete innovations [3].

The use of chemical admixtures is common in civil engineering constructions to modify concrete for specific uses, and general improvement on the performance of concrete structures. However, in developing regions, there is often a lack of supply of these admixtures, which impacts negatively on its availability and sustainable use [3]. Researchers have therefore turned attention to the use of naturally occurring admixtures which is available abundantly, cost-effective, environmentally friendly, and can be processed locally. A couple of local alternatives which have been investigated for this purpose include Gum Arabic karoo by [4, 5], Black liquor by [6], welan and neem gum by [7], bamboo leaf ash by [8] and corn starch by [9]. The use of locally-sourced alternatives for use as admixtures in modifying the properties of concrete has become essential due to the need to reduce dependence on chemical admixtures.

Cassava (*Manihot esculenta Crantz*), is a woody shrub which is grown in tropical and sub-tropical countries because of its roots, which are high in starch content. According to the study [10], its worldwide production forecast in 2018 is about 277 million tonnes, with 13.55 million tonnes processed for industrial use. Cassava Starch (CS), which is one of the products of cassava processing, has suitability to specific industrial applications because of the physicochemical properties of its granules [11]. CS has been defined as a carbohydrate that is classified as complex sugar with high molecular mass [12]. It is a white powder with no smell or taste [12]. It contains two molecular components: linear amylose and branched amylopectin [13]. The interaction between the amylose and amylopectin accounts for the textural and pasting properties of CS. CS is either locally extracted from the slurry of grated fresh cassava tubers or from milling peeled dry cassava tubers that are usually grown by subsistence farmers [14].

Polysaccharides such as cellulose ethers have been investigated to have a retarding effect on cement, which can be ascribed to the adsorption of its polymers with the silicate hydrates cement hydration [15, 16]. Adding to this is the effect of its hydroxyl group, which causes complexation of $Ca^{2+}$, thereby delaying hydration progress as suggested by [17]. Retardation is particularly important during concrete works in hot climates. CS, when activated, forms a viscous, sticky and jelly-like fluid that helps control fluid loss as reported by [18]. It has been noted that CS has high thickening power, which increases viscosity when added to cement paste [19]. Viscosity Modifying Admixtures (VMA) improve further hydration, internal curing and inhibit the formation of unwanted hydration products in cement paste [20]. This makes cassava starch worthy of consideration for investigation as an admixture due to its retarding and viscosity modifying ability. The organic nature of CS makes it susceptible to biodegradability and may have a negative effect on the durability of concrete. However, it has been concluded that the use of starch admixture improved the durability of concrete over the control over a testing period of 365 days [21]. The application of CS as an admixture in concrete will solve the challenge of availability, cost and sustainable use of admixtures in concrete for developing countries, thereby serving as an alternative for the use of chemical admixtures. Therefore, the primary objective of this work is to investigate the effect of CS on cement in terms of its setting time, workability, and mechanical properties of concrete.

## 2. MATERIALS AND METHODS

### 2.1. Materials

The material used for this investigation were Cassava Starch (CS), Fine Aggregates (FA), Coarse Aggregates (CA), Ordinary Portland Cement (OPC) type 1, Naphthalene superplasticizer and water. Fig. (**1**) shows the Cassava Starch used in this study. All the materials used in the study were obtained in Kenya except for Cassava Starch, which was procured in Ile-Ife, Nigeria. Potable water was used as the mixing water.

**Fig. (1).** Cassava Starch.

### 2.2. Methods

The particle size distribution of the coarse and fine aggregates was done in accordance with BS EN 933-1:2012 [22] in order to determine its suitability for use in concrete. The codes of practice adopted to carry out the other properties of aggregates are listed in Table **1**. The chemical analysis of OPC Type 1 of grade 42.4N was carried out using an X-Ray Fluorescence machine conforming to BS EN 196-2:2013 [23]. The compressive strength was determined using strength prism tests. The other physical properties such as consistency, specific gravity, initial and final setting times were determined in accordance with the standard code of practice listed in Table **1** and reviewed to check its conformity with the specifications of BS EN 197-1:2011 [24].

CS was dried in direct sunlight before use. The particle size was determined using a Laser Diffraction Particle Size Analyser (LDPSA), which uses a light scattering technique to measure the sizes of sediments such as clay mud and starches. Each percentage fraction of CS by weight of cement was activated using 10% of the mixing water at 70°C as proposed by [21] and allowed to cool to room temperature before mixing with the concrete. Fig.(**2**) shows the activated CS used for this study.

**Table 1. Material characterization and adopted codes for test method.**

| Test on Aggregates | | Test on Cement | |
|---|---|---|---|
| **Property** | **Adopted Standard** | **Property** | **Adopted Standard** |
| **Grading Analysis** | BS EN 933-1:2012 | Compressive strength | BS EN 196-1:2016 |
| **Specific Gravity** | BS EN 1097-6:2013 | Initial and Final setting time | BS EN 196-3:2016 |
| **Unit Weight** | BS EN 1097-3:1998 | Consistency | ASTM C187-10 |
| **Water Absorption** | BS EN 1097-6:2013 | Specific gravity | ASTM C188-17 |
| **Voids in Aggregate** | BS EN 1097-3:1998 | - | - |
| **Moisture Content** | BS EN 1097-5:2008 | - | |
| **Silt Content** | ASTM C33 | - | - |

**Fig. (2).** Activated CS.

**Table 2. Mix proportioning of concrete.**

| Mix No. | Cement (Kg/m$^3$) | W/C ratio | Fine Aggregate (Kg/m$^3$) | Coarse Aggregate (Kg/m$^3$) | Cassava Starch content (%) | Super-Plasticizer (%) |
|---|---|---|---|---|---|---|
| Control | 436 | 0.49 | 668.4 | 1002.6 | 0.0 | 0.75 |
| CS 0.4 | 436 | 0.49 | 668.4 | 1002.6 | 0.4 | 0.75 |
| CS 0.8 | 436 | 0.49 | 668.4 | 1002.6 | 0.8 | 0.75 |
| CS 1.2 | 436 | 0.49 | 668.4 | 1002.6 | 1.2 | 0.75 |
| CS 1.6 | 436 | 0.49 | 668.4 | 1002.6 | 1.6 | 0.75 |
| CS 2.0 | 436 | 0.49 | 668.4 | 1002.6 | 2.0 | 0.75 |

The mix design was carried out in accordance with BS 8500-2:2012 [25]. The water-cement ratio of 0.49, the aggregate content, and superplasticizer of 0.75 by weight of cement were used and kept constant for all mixes. The activated cassava starch was added at an increment of 0.4, starting from the control with 0% CS to 2.0% of Cassava Starch-Modified Concrete (CSMC). The highest percentage of CS addition was kept at 2% which is in line with clause 5.2.6 of BS EN 206:2013 [26]. The starch was added by weight of cement. The details of the proportioning are shown in Table **2**.

90 concrete cubes of size 100 mm x 100 mm x 100 mm were moulded for determination of compressive strength, 18 cubes of size 150 mm x 150 mm x 150 mm were moulded for determination of water absorption and density. 108 cylinders were cast for the determination of split-tensile strength and modulus of elasticity, while 18 beams of size 150 mm x 150 mm x 530 mm were cast for determination of flexural strength of unreinforced concrete. The concrete was cast and cured for 7, 14, 28, 56 and 90 days in accordance with the requirements of BS EN 12390:2-2009 [27].

(i.) The workability of the fresh concrete mix was determined using slump and compacting factor values. The tests were carried out in accordance with the requirements of BS EN 12350:2-2009 [28] and BS EN 12350:4-2009 [29], respectively.

(ii.) The density was determined in accordance with BS EN 12390:7-2009 [30].

(iii.) The compressive strength was determined using concrete cubes in accordance with BS EN 12390:3-2009 [31] and BS EN 12390:4-2000 [32] using a load-controlled universal testing machine for each curing age. This is shown in Fig. (**3**) .

(iv.) The split tensile strength was measured using concrete cylinders in accordance with BS EN 12390:6-2009 [33], using a load-controlled universal testing machine for the different mixes at each curing age.

(v.) The flexural strength was determined using rectangular concrete beams of size 150 mm x 150 mm x 530 mm in accordance with BS EN 12390:5-2009 [34], using a load-controlled universal testing machine at 28 days of curing. This is shown in Fig. (**4**).

(vi.) The static modulus of elasticity was determined by attaching two strain gauges (PL-60-11-3LT series) at diametrically opposite points at the mid-height surface of the concrete cylinder specimen and connected to a data logger to measure the longitudinal and transverse strain, respectively. The specimen was placed on a load cell, also connected to the data logger, to obtain the stress on the specimen. Fig. (**5**) shows the test setup The test was carried out in accordance with the requirements of ASTM C469-02 [35]. All the measured values are a mean of three samples.

An analysis of variance was carried out at a significance level of 0.05 in order to study the significance of the effect of CS on the compressive strength, split tensile strength, flexural strength, density and elastic modulus of concrete.

## 3. RESULTS AND DISCUSSION

### 3.1. Material Characterization

Coarse aggregates (CA), Fine Aggregates (FA) and cement were characterized in terms of the properties listed in Table **1** of Section 2.2. The particle size distributions for CA and FA are shown in Figs. (**6 and 7**), respectively.

The particle size distribution for CA as illustrated in Fig. (**6**), showed that 91.29% of CA was found between 5 mm and

25 mm aperture size. The envelope is also seen to be between the upper and lower limits, respectively, as stipulated in BS 882:1992 [36]. A well-graded aggregate ensures a workable concrete and reduces the tendency for concrete to segregate, bleed and undergo plastic shrinkage cracking [37]. The other physical properties of CA are shown in Table **3**. They are important material parameters required for the design and proportioning of quality concrete mixes. They are found to be within acceptable limits, which confirm its suitability for use for normal-weight concrete.

**Fig. (3).** Test of compressive strength of CSMC.

**Fig. (4).** Test of flexural strength of CSMC.

The particle size distribution for FA is shown in Fig. (**7**).

The envelope showed that the grading of FA is between the acceptable limits as specified in BS 882:1992 [36]. A well-graded fine aggregate ensures a close-packing characteristic of the combined aggregate within concrete. This reduces the tendency for defectiveness in concrete, such as honeycombs. The fineness modulus was found to be 2.40, which is within the range of 2.3-3.1, as specified in ASTM C33:2003 [38]. This affects the proportion of fines required in specifying workable concrete mixes. Other material properties of FA are listed in Table **4** and checked to confirm its suitability for use in normal-weight concrete.

From the data presented above, the silt content was found to be 4.87, which is lower than 5% according to specification. While it is not possible to single out an aggregate property that is responsible for the mechanical behaviour of concrete, an array of properties like voids in aggregate, moisture content and absorption influence the bond strength between the aggregate and cement paste [39].

**Fig. (5).** Test of Static modulus of elasticity of CSMC.

**Table 3. Physical properties of coarse aggregates.**

| Property | Value | Specification (ASTM C33 Limit) |
|---|---|---|
| Specific Gravity (SSD) | 2.41 | 2.4 - 2.9 |
| Unit Weight (Bulk density) | 1473.86 | 1200-1750 kg/m3 |
| Water Absorption | 3.11 | < 4% |
| Voids in Aggregate | 35.62% | 30-45% |
| Moisture Content | 3.69% | 0 - 4% |

**Table 4. Physical properties of fine aggregate.**

| Property | Value | Specification (ASTM C33 Limit) |
|---|---|---|
| Specific Gravity (SSD) | 2.41 | 2.4 - 2.9 |
| Unit Weight (Bulk density) | 1513.2 | 1200-1750 kg/m3 |
| Water Absorption | 2.81% | < 4% |
| Voids in Aggregate | 36.25% | 30-45% |
| Silt Content | 4.87% | < 5% |
| Moisture Content | 3.62% | 0 - 4% |
| Fineness Modulus | 2.40 | - |

The physical properties of cement are shown in Table **5** and found to conform with the requirements of BS EN 197:1-2011 [24], which confirms its suitability for use as a binder in concrete.

The chemical analysis of cement as shown in Table **6**, was found to be within the specified limits of BS EN 197:1-2011 [24]. The most important chemicals in cement are calcium oxide, silicon oxide, aluminium oxide, iron oxide and sulphur, respectively. Calcium oxide and silicon oxide are the most important chemicals which are responsible for the strength development in concrete. Aluminium oxide and iron oxides are responsible for the set properties of concrete, while sulphur, as found in gypsum, aids the formation of ettringite, which is not a desirable product during cement hydration. Also, the ratio of the calcium oxide to silicon oxide was found to be 2.38, which is greater than 2 as specified in clause 5.2.1 of BS EN 197:1-2011 [24]. The initial and final setting time measured compares well with the report of [40]. The total clinker constituent of the cement, as determined by Bogue's equation, was found to be 95.21%, which is more than 95% requirement, as seen in Table **1** of BS 197:1-2011 [24]. The percentage of Di-calcium silicates $C_2S$ in the clinker was found to be 63.96%, which is more than 13.25% for Tri-calcium silicates $C_3S$. Due to this, the concrete is expected to have a long term significant strength beyond 28 days, where concrete is supposed to have gained 99% of its strength as proposed by various codes.

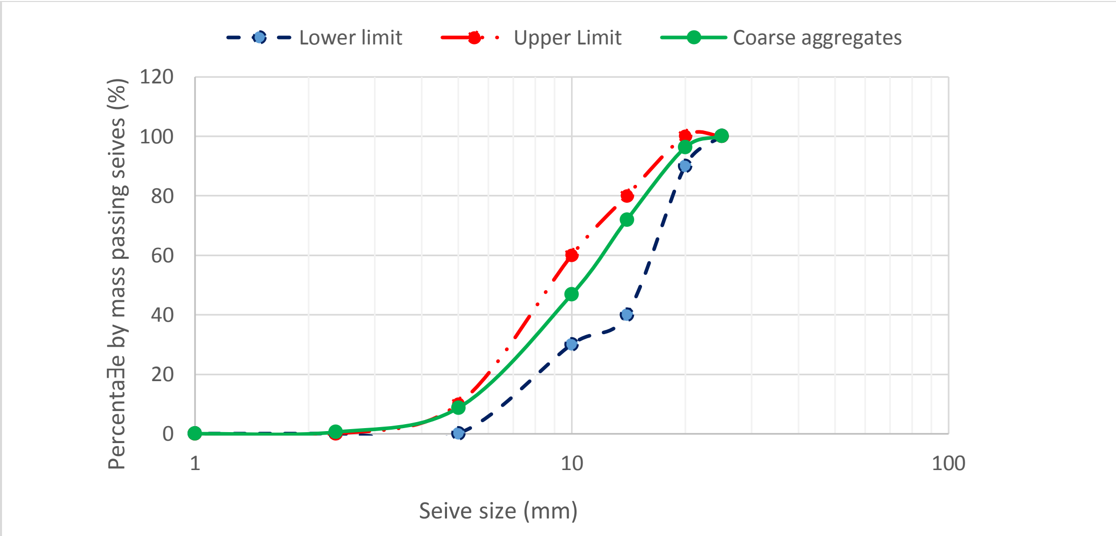


**Fig. (6).** Particle size distribution for coarse aggregates.

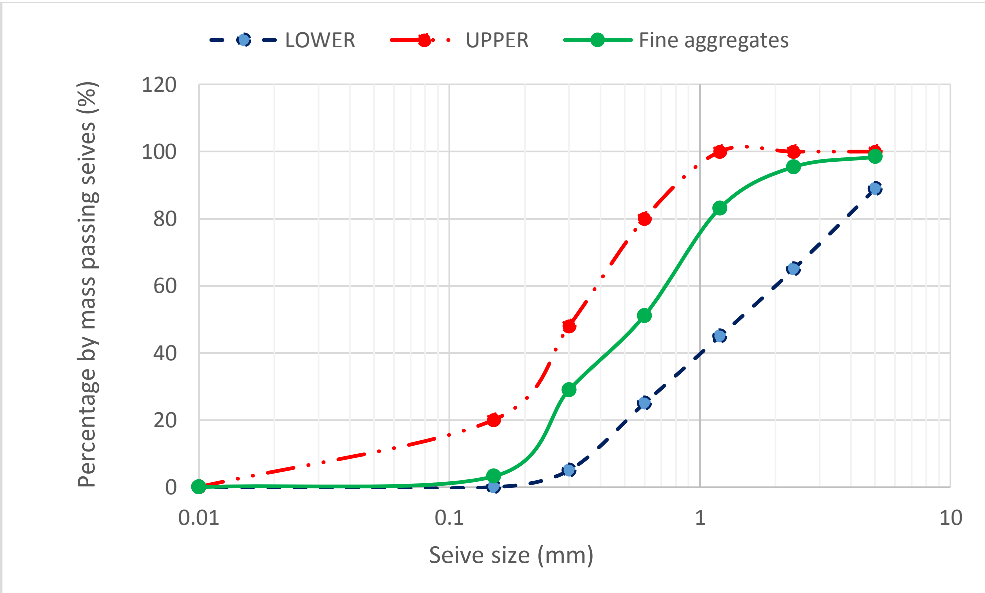


**Fig. (7).** Particle size distribution for fine aggregates.

**Table 5. Physical properties of cement.**

| Property | Value | Limits |
|---|---|---|
| Compressive strength at 2 Days | 13.87 | > 10N/mm$^2$ |
| Compressive strength at 28 Days | 46.23 | > 42.5N/mm$^2$ |
| Specific gravity | 3.11 | 3.10 -3.15 |
| Consistency | 32.75 | - |
| Initial setting time | 155 | ≥ 60 minutes |
| Final setting time | 248 | ≤ 375 minutes |
| Colour | Grey | - |

**Table 6. Chemical composition of cement.**

| Compound | Abbreviation | % Weight | Limits |
|---|---|---|---|
| Calcium oxide | $CaO$ | 61.48 | > 50 |
| Silicon oxide | $SiO_2$ | 25.79 | > 25 |
| Aluminium oxide | $Al_2O_3$ | 5.60 | - |
| Iron oxide | $Fe_2O_3$ | 2.34 | - |
| Sulphur | $SO_3$ | 2.60 | ≤ 3.5 |
| Potassium oxide | $K_2O$ | 1.00 | - |
| Phosphorus pentoxide | $P_2O_5$ | 0.52 | - |
| Chloride | Cl | 0.23 | - |
| Titanium | Ti | 0.21 | - |
| Strontium | Sr | 0.14 | - |
| ***Clinker Constituents as Determined by Bogue's Equation*** | | | |
| Tricalcium silicate | $C_3S$ | 13.25 | - |
| Dicalcium silicate | $C_2S$ | 63.96 | - |
| Tricalcium aluminate | $C_3A$ | 10.88 | - |
| Tetracalcium aluminoferrite | $C_4AF$ | 7.12<br>**95.21** | **-**<br>**95-100%** |

Table **7** shows the physical and chemical properties of the superplasticizer used in this research in conformity with BS EN 934:2 [41].

**Table 7. Properties of Superplasticizer.**

| Property | Value |
|---|---|
| Appearance/Colour | Dark brown liquid |
| Density (kg/L) | 1.2 ± 0.02 |
| Chemical Base | Naphthalene formaldehyde sulphonate |
| pH | 8 ± 1 |
| Chloride Content | < 0.1% |
| Dosage | 0.5 – 3% by weight of cement |

The particle size analysis of CS, as determined using an LDPSA, is shown in Fig. (**8**).

The mean particle size is found to be 15.275µm, while its specific surface is 4921.8cm$^2$/g. This result is higher than researchers who reported an average mean particle size and a specific surface of 14.294µm and 4440 cm$^2$/g, respectively. The fineness of CS characterised by its high specific surface area will increase the adsorption of more starch granules onto the surfaces of cement and covering of the cement grains [21]. This will increase its effect on the properties of concrete.

## 3.2. Physical Properties of Cassava Starch-Modified Concrete (CSMC).

### *3.2.1. Workability of CSMC*

The results of the workability on different mixes of CSMC which were measured using slump and compacting factors are shown in Table **8**.

The data showed a progressive decrease in both the slump and compacting factor of CSMC as the percentage of starch was increased, as illustrated in Fig. (**9**), while other mix variables were kept constant.

The slump and compacting factor values were reduced from 98 mm and 0.96 to 18 mm and 0.80, respectively. The reduction in the workability of CSMC can be linked to the viscosity modifying properties of Cassava Starch because of its thickening power. This caused an increase in the internal friction of the cement paste within the concrete, thereby leading to a reduction in the flowability of the resulting concrete mix. At 1.6% and 2.0% addition of CS, the resulting concrete as characterized by low slump and compacting factor values will require extra work in order to achieve good compaction when compared with the other mixes. This is expected to cause a decrease in the density of concrete and the strength characteristics of concrete at 1.6% and 2.0% addition of CS in concrete due to the direct relationship that exists between the degree of compaction and strength. The results observed compare positively with the findings of [21] but disagrees with [42] who reported an increase in workability.

**Table 8. Slump and compacting factor value of CSMC.**

| CSMC (%) | Slump (mm) | Compacting Factor | % Reduction in Slump | % Reduction in Compacting Factor |
|---|---|---|---|---|
| 0.0 | 98 | 0.96 | 0.00 | 0.00 |
| 0.4 | 75 | 0.94 | 23.47 | 2.41 |
| 0.8 | 64 | 0.92 | 34.69 | 4.58 |
| 1.2 | 34 | 0.85 | 65.31 | 11.92 |
| 1.6 | 29 | 0.82 | 70.41 | 14.61 |
| 2.0 | 18 | 0.80 | 81.63 | 16.56 |

### *3.2.2. Initial and Final Setting Time of Cement Admixed with CS*

The results of the setting time of cement paste mixed with cassava starch are shown in Fig. (**10**).

The initial and final setting time, which is the time elapsed when cement begins to lose its plasticity, and when loses all of its plasticity [43], is of great importance to aid effective handling of concrete during construction. The data showed a progressive increase in both the initial and final setting time of cement paste from 155 and 248 minutes to 248 and 436 minutes, respectively, as the percentage of CS increased from 0.0% to 2.0%. This is in line with [44] who noted that retardation in cement increases with high polysaccharide to cement ratio. The increase in the initial setting time and final setting times for each percentage addition of CS over the control are 32 minutes, 43 minutes, 54 minutes, 82 minutes, 93 minutes and 58 minutes, 77 minutes, 94 minutes, 141 minutes, 188 minutes, respectively. This retarding effect can be ascribed to be due to the adsorption of starch polymers to the Tri-calcium Aluminates ($C_3A$), which is responsible for the set properties of cement paste as far as cement hydration is concerned [15, 16]. Adding to this is the effect of the hydroxyl group of starch, which aids preferential complexation of $Ca^{2+}$, thereby leading to a delay in the hydration progress, as suggested by [17]. The results shown are in agreement with the report of [14, 21, 42]. It is important to note that the delay in the setting of concrete is experienced within 24 hours of hydration of cement paste. The retention times of the concrete admixed with CS (from 0.4% to 2.0%) over the control before it starts losing its plasticity are 32 minutes, 43 minutes, 54 minutes, 82 minutes, and 93 minutes, respectively. The retention times of CSMC over the control before it loses all of its plasticity are 58 minutes, 77 minutes, 94 minutes, 141 minutes, and 188 minutes, respectively. This means that concrete can be worked upon without breaking the bond that exists between the aggregate-cement paste interphase. This is because any further work on cementitious mixtures beyond the initial and final setting times can lead to a reduction in the overall strength of concrete. This is particularly important for concrete works during hot weather.

## 3.3. Mechanical Properties of CSMC

### *3.3.1. Compressive Strength of CSMC*

A key indicator used in evaluating the performance of concrete is its compressive strength. The results of the compressive strength test of CSMC at both 7, 14, 28,56 and 90 days are showed in Fig. (**11**).

The compressive strength increased above the control at all percentage addition of cassava starch at 7, 14, and 28 days of curing. The increment seen up to 28 days curing can be linked to the reduced tendency of bleeding and segregation in concrete due to the viscous nature of CS. The viscosity modifying properties of CS also help improve internal curing, degree of hydration and prevent the formation of undesired hydration products such as ettringite in concrete. A significant development in strength is noted for all mixes beyond 28 days of curing. This can be ascribed to the greater percentage of di-Calcium Silicates ($C_2S$), which is responsible for long term strength development, over the tri-Calcium Silicates ($C_3S$) responsible for early strength development. At 56 and 90 days of curing, 0.4%, 0.8% and 1.2% Cassava Starch addition showed an increased strength over the control, while the other dosage additions showed a slight decrease in strength below that of the control. The compressive strength for all mixes peaked at 0.8% addition of CS for all days of curing. This result compares positively with the findings of [21, 42, 45]. The results of the two-way analysis of variance carried out to study the significance of the effect of CS and curing age on the compressive strength of concrete are presented in Table **9**.

**Table 9. Two way analysis of variance for compressive strength of concrete.**

| Source of Variation | SS | df | MS | F | *P*-value | F crit |
|---|---|---|---|---|---|---|
| **Curing Days** | 5557.319 | 4 | 1389.33 | 305.1365 | 3.93E-39 | 2.525215 |
| **CS Addition** | 377.0152 | 5 | 75.40305 | 16.56066 | 3.03E-10 | 2.36827 |
| Interaction | 166.0313 | 20 | 8.301564 | 1.823261 | 0.038434 | 1.747984 |
| Within | 273.1885 | 60 | 4.553141 | - | - | - |
| Total | 6373.554 | 89 | - | - | - | - |

The analysis for the curing days showed that the F value was found to be 305.1365, which is significantly higher than the F-critical value of 2.5252 and the *P*-value of 3.93E-39 is lesser than the significance level of 0.05. This showed that the days of curing affect the compressive strength of concrete. Also, the F value for CS addition was found to be 16.5607 which is higher than the F-critical value of 2.3683 and the *P* - value of 3.03E-10 is lesser than the significance level of 0.05. This shows that CS affects the compressive strength of concrete. For the interaction between the addition of CS in concrete and the curing, the F-value of 1.8233 was found to be higher than F-critical of 1.780, while the P-value of 0.03 was lesser than 0.05. This suggests that the addition of CS in concrete has an impact on the curing of concrete.

### *3.3.2. Split-tensile Strength of CSMC*

The results of the split tensile strength of concrete are illustrated in Fig. (**12**).

A general increase in strength of the control concrete and CSMC is observed with an increase in curing age. This is due to further hydration and strength gain. The figure shows that there is an increase in the split tensile strength of CSMC over the control concrete for up to 28 days of curing, as the percentage of Cassava Starch increases. The increase in tensile strength can be linked to the ability of CS to control bleeding in concrete, thereby reducing the formation of microcracks or shrinkage cracks at the paste-aggregate interphase, as suggested by the study [43]. The maximum split tensile strength recorded at 28 days of curing was 2.96 MPa for 0.8% CS addition, which represents a 12.55% increase over the control. However, at 56 and 90 days of curing, only 0.4%, 0.8% and 1.2% CS showed an increase in strength over the control. The decrease in strength noticed at 1.6 and 2.0% CS may be due to the overly thick starch gel, which could form mud cakes in concrete. A relationship between the compressive strength and split tensile strength is presented in Fig. (**13**).

Based on the results, a non-linear relationship $f_t = 0.3121 f_c^{0.624}$ was derived between the compressive and split tensile strength using a power curve. It generally shows an increasing trend in agreement with empirical relations proposed by ACI 318-99 [46 - 48]. The power co-efficient 0.624, which is higher than 0.5 proposed by [46, 48] suggests a positive effect of CS on the rate of improvement between successive mixes of CSMC over the control. The results of the two-way analysis of variance carried out to study the significance of the effect of CS and curing age on the split tensile strength of concrete is presented in Table **10**.

**Table 10. Two way analysis of variance for split tensile strength of concrete.**

| Source of Variation | SS | df | MS | F | *P*-value | F crit |
|---|---|---|---|---|---|---|
| **Curing Days** | 26.43042 | 4 | 6.607606 | 143.283 | 5.61E-30 | 2.525215 |
| **CS Addition** | 2.759795 | 5 | 0.551959 | 11.96898 | 4.71E-08 | 2.36827 |
| Interaction | 2.208698 | 20 | 0.110435 | 2.394731 | 0.004864 | 1.747984 |
| Within | 2.766947 | 60 | 0.046116 | - | - | - |
| Total | 34.16586 | 89 | - | - | - | - |

The analysis for the curing days showed that the F-value was found to be 143.283, which is significantly higher than the F-critical value of 2.5252 and the *P*-value of 5.61E-30 is lesser than the significance level of 0.05. This showed that the days of curing affect the split tensile strength of concrete. Also, the F value for CS addition was found to be 11.969 which is higher than the F-critical value of 2.3683 and the *P*-value of 4.71E-08 is lesser than the significance level of 0.05. This shows that CS affects the split tensile strength of concrete. For the interaction between the addition of CS in concrete and the curing, the F-value of 2.3947 was found to be higher than F-critical of 1.780, while the *P*-value of 0.0049 was lesser than 0.05 which suggests that the addition of CS in concrete has an impact on how concrete cures thus confirming the trend noticed with the compressive strength.

### *3.3.3 Flexural Strength of Unreinforced CSMC*

The results of the three-point flexural test on the unreinforced concrete beam to obtain its flexural strength at 28 days of curing are shown in Fig. (**14**).

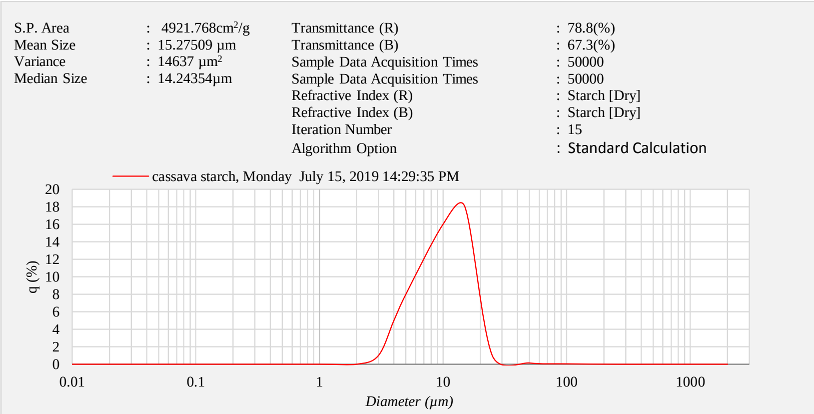


**Fig. (8).** Particle size distribution for CS.

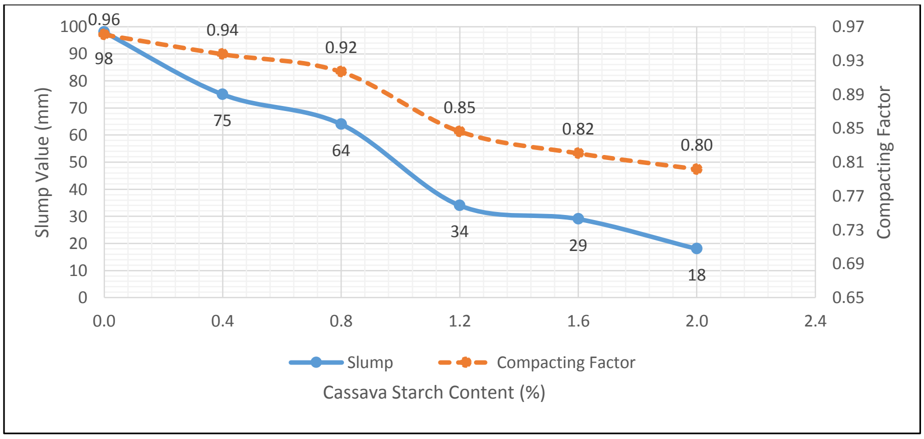


**Fig. (9).** Workability of CSMC.

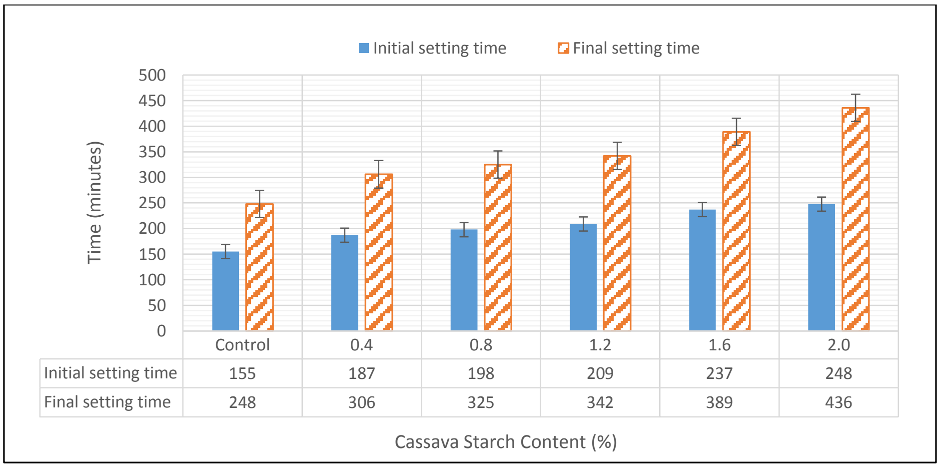


**Fig. (10).** Initial and final setting time of cement admixed with CS.

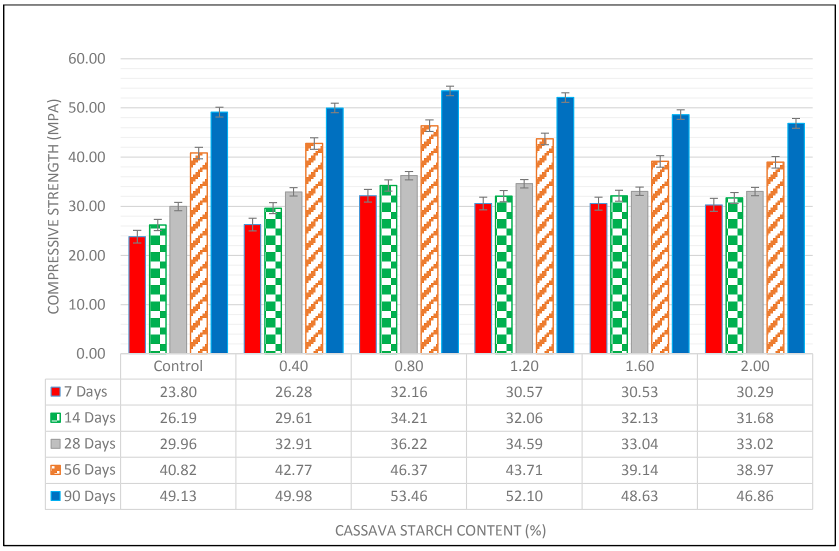


**Fig. (11).** Compressive strength of CSMC.

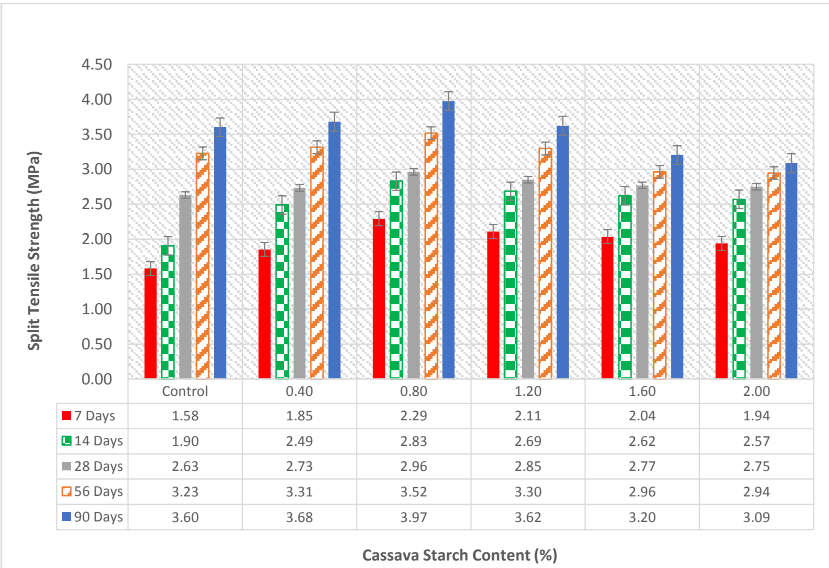


**Fig. (12).** Split-tensile strength of CSMC.

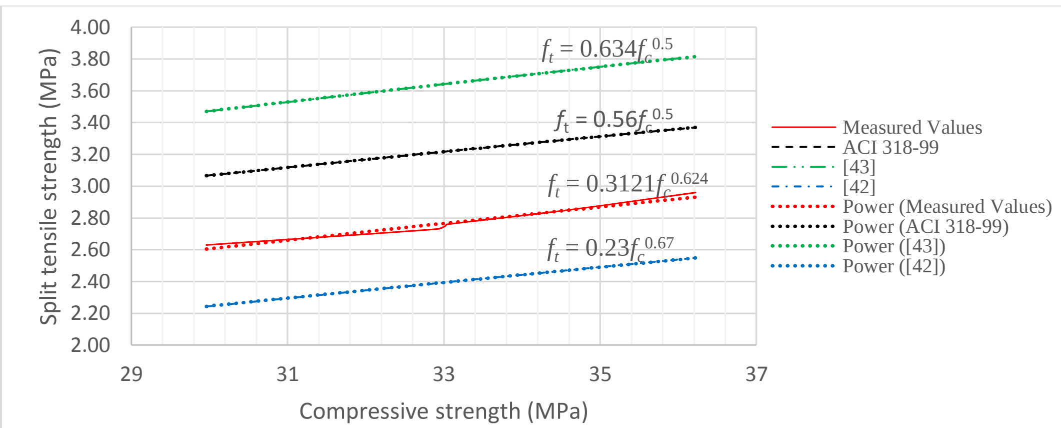


**Fig. (13).** Relationship between compressive strength and split tensile strength.

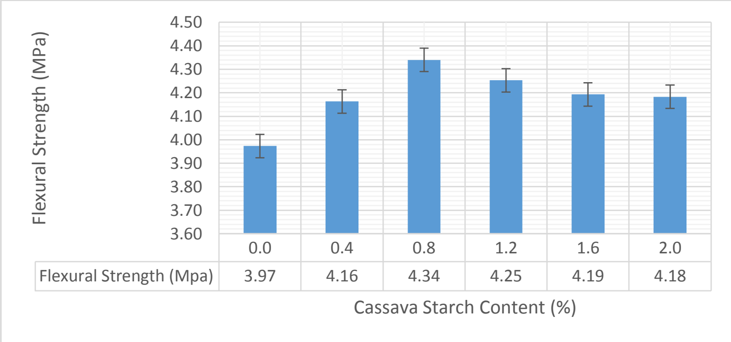


**Fig. (14).** Effect of Cassava Starch on flexural strength of unreinforced concrete.

The data showed that there is an increase in the flexural strength of CSMC for all percentage addition of Cassava Starch in comparison with the control concrete. The improvements are 4.78%, 9.32%, 7.05%, 5.54% and 5.29%, respectively. The gain in flexural strength of concrete can also be ascribed to the direct relationship between flexural and compressive strength of concrete through the relation "$f_{fs} = bf_c^{n}$" where b and n are correlation coefficients [49]. This compares well with the fact that the compressive strength of CSMC for all percentage addition of CS was more than the control at 28 days of curing. Another factor causing this trend can be linked to the bond strength at the interface between the cement paste and the aggregate known as the transition zone. A poor paste structure and weaker gel bond at the transition zone is said to be due to bleeding water, which accumulates at the transition zone according to [43]. This situation is more likely in the control mix compared to other mixes containing Cassava Starch. The optimum strength as observed, is proved by the fact that a peak in the compressive strength at 0.8% addition of cassava starch showed a corresponding peak in flexural strength at the same percentage addition of starch. The relationship between the compressive strength and flexural strength from the data is illustrated in Fig. (**15**).

The relationship between compressive strength and flexural strength is presented as $f_{fs} = 0.8186f_c^{0.4654}$. The increase can be linked to the increase in stiffness (EI) of the beam as the percentage of CS increased, which helps its resistance to bend stresses in addition to the reduction in microcracks within the concrete, as discussed in Section 3.3.2. The results of the one-way analysis of variance carried out to study the significance of the effect of CS on the flexural strength of concrete is presented in Table **11**.

### *3.3.4. Density of CSMC*

The result of the density of CSMC is illustrated in Fig. (**16**).

An increase in density was noticed up to 1.2% addition of cassava starch before a decline was observed for CS 1.6 and CS 2.0. The decline could be linked to the low workability values, as discussed in Section 3.2.1, which is a result of an inability to achieve better compaction over the other mixes. The density values for all the mixes were in the range of 2000 - 2600kg/m3 for normal concrete as required by BS EN 206:2013 [26]. The results of the one-way analysis of variance carried out to study the significance of the effect of CS on the flexural strength of concrete is presented in Table **12**.

**Table 11. One way analysis of variance for flexural strength of concrete.**

| Source of Variation | SS | df | MS | F | *P*-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 0.222111 | 5 | 0.044422 | 13.69178 | 0.000131 | 3.105875 |
| Within Groups | 0.038933 | 12 | 0.003244 | - | - | - |
| Total | 0.261044 | 17 | - | - | - | - |

The F-value of 13.6918 is higher than the F-critical value of 3.1059 and the *P*-value of 0.000131 is lesser than the significance level of 0.05. This shows that CS affects the flexural strength of concrete.

**Table 12. One way analysis of variance for concrete density.**

| Source of Variation | SS | df | MS | F | *P*-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 21656.89 | 5 | 4331.378 | 7.338145 | 0.002303 | 3.105875 |
| Within Groups | 7083.062 | 12 | 590.2551 | - | - | - |
| Total | 28739.95 | 17 | - | - | - | - |

The F-value of 7.3381 is higher than the F-critical value of 3.1059 and the *P*-value of 0.002303 is lesser than the significance level of 0.05. This shows that CS has a significant effect on the density of concrete.

### *3.3.5. Static Modulus of Elasticity of CSMC*

Modulus of elasticity of concrete, $E_c$ is an important material property used to estimate the deformation parameters of structural elements [50]. It is a ratio of the normal stress to strain below the limit of proportionality of the material. Different design codes like ACI 318-14 [51], IS 456 [52], BS 8110:2 [53], EC2 [54] and CSA A23.3-40 [55] have presented relations for predicting the elastic modulus of concrete from its compressive strength. Recent studies have shown that there may be variations from the proposed relations, which are presented in Table **13**.

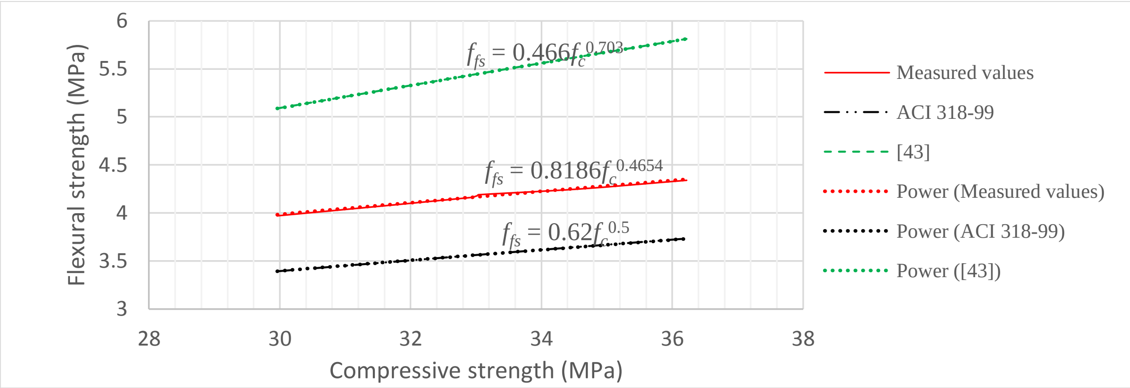


**Fig. (15).** Relationship between compressive strength and flexural strength.

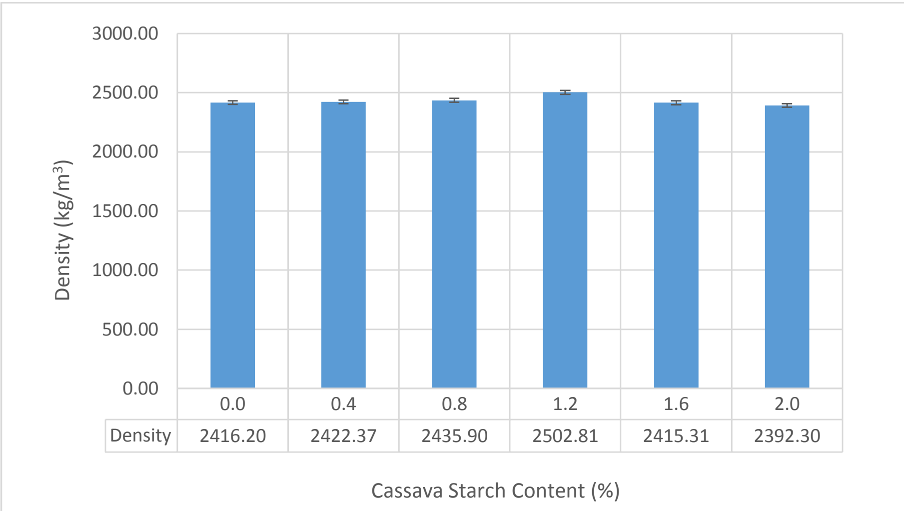


**Fig. (16).** Density of CSMC.

**Table 13. Relations between compressive strength and elastic modulus of concrete.**

| Designation | Equation | Validity |
|---|---|---|
| ACI 318-14 | - | USA |
| IS 456 | - | India |
| BS 8110:2 | $k_o + 0.2 f_{cu,28}$ | Great Britain |
| EC2 | $22[(f_{cm})/10]^{0.3}$ | Europe |
| CSA A23.3 | - | Canada |

The measure of the elastic properties of concrete as determined by uniaxial compression of cylinder specimens of all mixes, gave the data presented in Table **14**.

The highest mean value of $E_c$ was 25,512.80 MPa for CS 0.8 which represented a 15.06% increase over the lowest mean value was 22,173.86 MPa for the control concrete. This improvement can be ascribed to the positive effect of CS on the bond strength at the cement aggregate interphase, which leads to an increase in the strength properties of concrete and the stiffness of CSMC. The relationship between the compressive strength and static elastic modulus of concrete from the data in comparison with predicted values from standard codes of practice is illustrated in Fig. (**17**).

The measured values of $E_c$ show a non-linear relationship between the compressive strength and static elastic modulus of concrete through the relation of $E_c = 3825.5 f_c^{0.5488}$. This compares well with the general trend observed in the relations proposed by design codes listed in Table **10**, stating a direct relationship between elastic modulus and strength. The values, as determined by experiments, agree closely with the relation from CSA A23.3 [50]. The results of the one-way analysis of variance carried out to study the significance of the effect of CS on the flexural strength of concrete is presented in Table **15**.

**Table 14. Static elastic modulus of CSMC.**

| Mix | Modulus of Elasticity (MPa) | Change in $E_c$ (%) | Compressive Strength (MPa) |
|---|---|---|---|
| CS 0.0 | 22173.86 | 0.00 | 24.58 |
| CS 0.4 | 23607.00 | 6.46 | 26.82 |
| CS 0.8 | 25512.80 | 15.06 | 30.30 |
| CS 1.2 | 25013.71 | 12.81 | 29.79 |
| CS 1.6 | 23713.67 | 6.94 | 29.28 |
| CS 2.0 | 23700.48 | 6.88 | 29.11 |

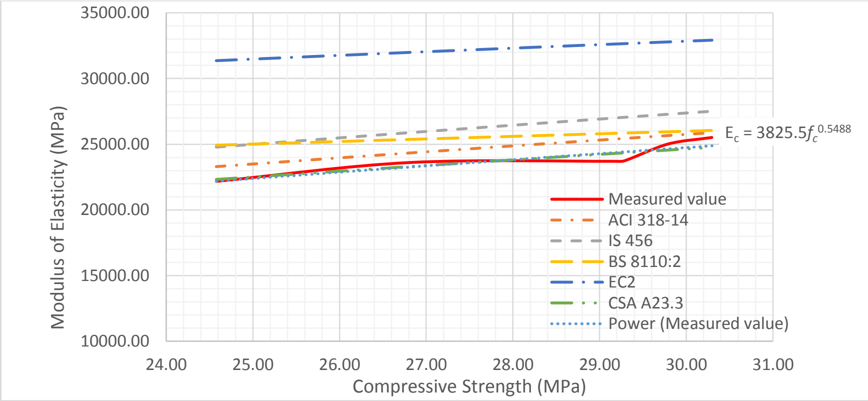


**Fig. (17).** Comparison between measured and predicted values of $E_c$.

**Table 15. One way analysis of variance for static modulus of elasticity of concrete.**

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 13928846 | 5 | 2785769 | 128.0379 | 5.2E-06 | 4.387374 |
| Within Groups | 130544.2 | 6 | 21757.37 | - | - | - |
| Total | 14059391 | 11 | - | - | - | - |

The F-value of 128.0379 is higher than the F-critical value of 4.3874 and the *P*-value of 5.2E-06 is lesser than the significance level of 0.05. This confirms the effect of cassava starch on the static modulus of elasticity of concrete.

## CONCLUSION

Based on the results of this study, the following conclusions were made:

1. The workability of concrete is reduced with an increase in CS content.

2. The setting time of cement paste increased with an increase in percentage addition of CS.

3. A retention time of 1 hour 17 minutes was observed for the ideal mix at 0.8% addition of CS over the control, which gives an additional time for concrete to be worked without affecting its strength properties.

4. The compressive strength, split tensile strength, flexural strength and static modulus of elasticity increased with an increase of CS content.

5. Cassava Starch can be considered as a viscosity modifying admixture in concrete in addition to its retarding properties.

Therefore, CS can be ideally used as an admixture at 0.8% addition by weight of cement in concrete based on its ability to modify the physical and mechanical properties of concrete.

## AUTHOR'S CONTRIBUTIONS

D.O.O. and J.M. designed the experiments; D.O.O. performed all the experiments; D.O.O., J.M. and C.K. analyzed the experimental results; D.O.O. wrote the Paper; J.M. and C.K. reviewed and edited the final paper.

## CONSENT FOR PUBLICATION

Not applicable.

## AVAILABILITY OF DATA AND MATERIALS

Not applicable.

## FUNDING

None

## CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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