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Analysing the Effect of Cassava Flour as a Mixture on the Physical, Mechanical, and Durability Properties of High-Strength Concrete

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Abstract

The availability, cost, and environmental impact of chemical admixtures are reduced when natural substitute materials are incorporated into the concrete as an admixture. This paper outlines the findings of a study that looked at the physical characteristics of fresh and hardened concrete made with Portland pozzolanic cement CEM II/B-P blended with cassava flour up to 5% by weight of cement. A low water/binder ratio of 0.35 was used together with a carboxylate-based superplasticizing admixture to produce high strength. In fresh-state concrete, the initial and final setting times, soundness, and consistency were found to increase with increased cassava flour content, whereas the compacting factor and slump were observed to decrease. In the hardened state, compressive strengths were determined at 3, 7, 14, 28, 56, and 90 days, while split tensile and flexural strengths were investigated at 28 days. Similarly, dry density and porosity were also investigated at 28 days. Water absorption was also studied as a potential indicator of durability in hardened concrete. Scanning electron microscopy characterization of cassava flour revealed porous particles of irregular shape. On the other hand, X-ray diffraction imaging showed that the primary chemicals in cassava flour are silicon dioxide (50%), calcium oxide (17%), and aluminium oxide (7%). All of the mixes that incorporated cassava flour were stronger than the control mix, with the 3% cassava flour combination producing the best results.

Keywords: Portland Pozzolanic Cement; Cassava Flour; Workability; Bulk Dry Density; Water Absorption.

1. Introduction

The demand for construction materials, especially concrete, increases as a consequence of socioeconomic considerations in infrastructure development and the continuous increase in the global population [1, 2]. Due to its desirable mechanical and durability characteristics, widespread availability, simplicity of application, affordability, low maintenance requirements, fire resistance, and environmental friendliness [3], concrete has been a standard construction material since ancient times and is used in various construction applications, such as bridges, dams, and rigid and flexible pavements [4, 5]. New types of concrete are continually developed to meet the increasing demand for improved mechanical and durability properties, such as high-strength concrete (HSC) and high-performance concrete (HPC) [6, 7]. A concrete that has high strength provides maximum compression resistance that is higher than

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the normal strength range specified in the design codes. HSC is made using the same materials as normal concrete, namely, cement, fine aggregate, coarse aggregate, and a few mineral admixtures to give it the desired strength [5]. On the other hand, HPC meets unique performance and uniformity requirements, has high fluidity without segregation in the fresh state, high early strength with a 28-day cube crushing strength above 60 MPa, and high durability in the service environment when compared to conventional concrete [8]. The mechanical resistance, durability, and resistance to extra loads of the new composite high-performance concrete are significantly improved. Also, these high-performance materials can be used to construct special structures, like shell structures, which are stronger, thinner, and more flexible [9].

A significant contribution to global CO_2 emissions, high energy consumption, overexploitation of limestone, and potential environmental consequences is mainly due to the production of concrete using ordinary Portland cement (OPC) [10-14]. A case for using blended cements, which are manufactured from discarded thermal power plant waste materials such as fly ash [15], is that they are more environmentally friendly. Compared to standard OPC, Portland Pozzolanic Cement (PPC) is less expensive, has a higher compressive strength after 28 days, and has higher durability than OPC. As a result, it provides better structural performance and less permeability [16]. It fits well into concrete construction due to its excellent resistance to chemical attack, cracking resistance, lower heat of hydration, and better conservation of existing natural resources [17]. The demand for modification of specific properties of construction materials has grown with sophistication in design, the increasing cost of construction materials, new construction techniques, and greater sensitivity to regional and environmental factors [16]. Additives are sometimes used to modify specific properties of concrete mixes, such as the reduction in the porosity of cement paste, improving the interface between the paste and aggregate [18, 19], controlling the setting time, reducing water demand [20], and modifying the natural rheology of concrete [21-23].

As a result, chemical admixtures have improved the characteristics of concrete and increased its performance [24]. However, they are in short supply in developing countries due to low industrial activity, posing a threat to their availability and sustainable use [25]. In addition, chemical admixtures have the potential to pollute the environment during production, shipping, storage, or handling; usage in the construction of concrete structures; reuse of concrete after demolition; and disposal of construction debris and leftovers [26]. Therefore, some researchers have focused on using naturally occurring admixtures to improve the hardened and fresh properties of concrete, which are widely accessible, economical, eco-friendly, and may be processed locally to reduce dependence on imported chemical admixtures. Regional materials that have been investigated as concrete admixtures include corn starch [27], sorghum flour [28], Arabic Karoo gum [29, 30], okra extract and cypress tree [37, 38], and cassava starch [20–35]. Cassava is a woody tree that is grown in tropical and sub-tropical regions because of its roots, which contain a high percentage of starch. Based on a study by Okafor (2010) [36] and the Food and Agriculture Organization (FAO) of the United Nations, 2015 [37], its worldwide production in June 2022 was about 277 million tons, with 13.55 million tons being processed for industrial use. It can also be used as an animal feed ingredient, according to Surtono et al. (2019) [38].

The effectiveness of cassava flour as an additive for minimizing water content in concrete has been investigated by Okafor (2010) [36]. The work focused on the development of workability and compressive strength for all mixtures up to the age of 90 days. In his study, concrete mixes using three different dosage levels of 1, 2, and 3 of the admixture with four different water-cement ratios of 0.45, 0.50, 0.60, and 0.70 were used. The results showed improvement in the workability of concrete with an increasing amount of cassava flour in the concrete mixture. The increase in workability was caused by the presence of high-activity factors on the surface of the admixture that interacted with the cement particles and generated negative charges that led to the repulsion of the cement particles. The researchers also observed strength improvement with age in concrete with cassava flour addition compared to control concrete. The compressive strength of concrete containing cassava flour admixture increased with age in all situations, but it had lower strength than the control concretes up to the age of 14 days.

Other researchers, Akindahunsi & Uzoegbo (2015) [39], evaluated the durability and strength of concrete made from various plant starches, such as cassava and maize, and found that, the use of these starches reduced the setting time of cement paste but increased the concrete's ultimate strength and durability. On the other hand, Chu (2015) [19] experimented with a mixture of tapioca and maize flours when varying the amounts of one starch while holding the other constant. They found that the concrete with various concentrations of maize starch up to 1.5% performed better than the concrete with various concentrations of tapioca starch up to 2.5%. Similarly, Akindahunsi (2019) [20] used 0.2-2% starch extracted from maize and cassava as an admixture. The powders were processed in the factory and then activated with water at a temperature of 70–90 ^{o}C to convert them into a gelatinous substance. The starch was cooled and used in concrete, taking into account the amount of water used in activation and deducting it from the mixing water percentage. In this study, it was noted that the starch admixtures improved the strength and decreased the deformation of concrete. In addition, Akindahunsi & Schmidt (2019) [40] investigated the effect of cassava starch on the shrinkage characteristics of concrete by using cassava flour up to 2% of the weight of cement. According to these results, cassava starch positively affected the compressive strength and gave more stiffness in the form of cohesion and stability, resulting in reduced shrinkage in concrete. Other studies were conducted by Kone et al. (2022) [34], who investigated the effect of cassava starch and rice husk ash on the physical and mechanical properties of concrete containing 2% cassava starch added by the weight of cement and 20% rice husk ash replacement of cement. The RHA was burnt at temperatures of 650 °C, while cassava flour was used to prepare the starch. According to the study results, concrete workability decreased and the setting time was prolonged. In addition, the compressive and split tensile strengths were improved compared with the control mix samples.

Ikoko (2021) [41] examined the effect of cassava starch, sodium chloride, and sawdust as admixtures to improve the fresh and mechanical properties of concrete by using up to 2% cassava starch, 1% sodium chloride, and 0.75% sawdust. The results showed that concrete comprising cassava starch, sodium chloride, and sawdust was much stronger than concrete made from sawdust and cassava starch. When the amount of sawdust was increased to 3 kg, the hygroscopicity of the materials caused the slump of the concrete with cassava starch and sawdust to decrease. The slump value of the concrete with cassava starch, sawdust, and sodium chloride also decreased, but not as much as the concrete without sodium chloride. Sybis & Konował (2022) [42] the impact of cassava starch on the rheological characteristics of cement and how it influences the compressive strength of cement. This study made use of 17 different types of processed starch. The variables for viscosity and pressure that were used to calculate the viscosity of cement mortar were determined depending on the shear rate. The results demonstrated that the various amounts of modified cassava starch altered the rheology and compressive strength of cement. Additionally, a 13% reduction in compressive strength was noted as a result of the reduced mortar production brought on by the decomposition of the starch combination, which in turn caused the concrete mix to liquefy and use less water during mixing.

Stabilized earth bricks were researched by Souza et al. (2021) [43]. This study focused on the production of concrete bricks using 6% and 12% of ordinary Portland cement blended with potable and cassava effluent water. The results showed that after 49 days, concrete bricks blended with cassava effluent water had the highest compressive strength of 4.9 MPa and the lowest water absorption percentage of 12.91%. On the other hand, Adedokun et al. (2022) [44] investigated the effect of cassava liquid waste on the behaviour of concrete. In this study, the slump, compressive strength, and split tensile strength of samples made from cassava liquid wastewater and cured in potable water were determined. In addition, concrete was mixed with cassava water and treated with cassava water, and concrete was mixed with potable water and processed in cassava water. The results showed that cassava wastewater did not affect the slump values, whether as normal mixing water or treated water. However, cassava water affected the compressive and split tensile strengths, as it decreased the compressive strength and split strength of concrete.

Similarly, Uguru & Akpokodje (2019) [45] studied the effect of cassava liquid waste on the physical and mechanical properties of hard sand concrete blocks. Two groups of sand concrete blocks were cast using cassava wastewater and potable water. The mechanical properties of the sand concrete blocks were also studied after a curing period of 28 days, as were the initial physical properties of the materials used in mixing the earth blocks. The results indicated that cassava wastewater had a positive effect on the compressive strength and water absorption rate, as the compressive strength and absorption rate of sand concrete blocks made from cassava wastewater in 28 days reached 3.38 MPa and 4.73%, respectively, compared to those manufactured from potable water, which was measured 2.04 MPa and 8.10% of freshwater, respectively. On the other hand, Schmidt et al. (2018) [46] investigated the effect of plant-based admixtures on concrete properties. Cassava starch and acacia gum were used to test the rheology of cementitious materials in concrete, and the results showed that acacia gum is superplastic while cassava starch reduces yield stress. While other studies focused on the opposite, Sinkhonde et al. (2022) [47] used morphological measurements and 2-D shape descriptors to represent agricultural admixtures. The results showed that average values of solidity, roundness, circularity and an axial ratio of more than 0.7 were characteristics of the mineral admixtures.

The literature review adequately supports the possibility of using cassava flour as an additive in concrete. The researchers used cassava flour to examine some properties of concrete without any specific characterization of the cassava flour. In addition, there are several factors that can affect the results, such as the initial water/cement ratio, the type of cement, the texture of the flour, etc. It is impossible to draw accurate conclusions about concrete strength regarding cassava flour as an admixture in concrete production. This research sets out to study the effect of cassava flour when used with Portland pozzolanic cement at a low water/cement to enhance concrete strength and incorporate a super-plasticizing admixture to improve the workability of the concrete. No study of the effect of cassava flour under these conditions of use was found. Specifically, the research sets out to establish the following: What are the physical and chemical characteristics of cassava flour? What is the effect of cassava flour when used in concrete made with Portland pozzolana cement, and what is the optimum dosage of cassava flour under the specified conditions of use? It is very important to check the chemical composition, physical properties, and particle shape of the binding materials used in the concrete mix because of their important role in obtaining a high-quality concrete mix. However, the presence of different chemical compounds like magnesium may cause problems that damage the concrete structure during its service life. A scanning electron microscope and X-ray diffraction analysis were used to develop knowledge of the representative characteristics, particle morphology, and specific chemical compounds of cassava flour. Then, it was used as a percentage of Portland pozzolanic cement in different amounts ranging from 1 to 5% to make high-strength concrete and study both the properties of fresh and hardened concrete. Through this research, the concrete's compressive, split tensile, and flexural strengths will be improved by using Portland pozzolanic cement in both states. The accomplishment of this research will enhance the value of domestically sourced alternative materials. The challenges of chemical admixtures' affordability, sustainability, and availability can be addressed. In addition to encouraging the use of locally accessible substitute materials in construction, the use of cassava flour as an additive in concrete addresses issues of the expense and availability of chemical admixtures in developing countries. It's also very important to promote the use of cassava flour in different fields, especially in the field of the concrete construction industry.

2. Materials and Methods

2.1. Material

The cassava root used in this study was obtained from the Juja market in central Kenya. As a binder, Type II PPC, manufactured locally and conforming to EN 197, was used. Crushed granite rock with a maximum size of 12.5 mm was used as coarse aggregate (CA). Fine aggregate (FA) was river sand obtained from local suppliers. Sika Viscoflow-615KE Superplasticizer was used as a workability aid. Lastly, ordinary tap water of potable quality was used for all concrete mixes.

2.1.1. Test Methods for Materials Characterization

The particle size distribution of fine and coarse aggregates was examined to determine whether they were suitable for use in concrete [48]. Cassava roots were processed manually by chopping them into thin slices and then dried in an oven for 24 hours at 100 °C. The PSD for cassava flour was determined using a hygrometer test in accordance with ASTM D75/D75-19 [49]. In ASTM C128-01 [50], the specific gravity and water absorption of aggregates were examined. The bulk density and voids of aggregate were acquired using the methods recommended by ASTM C29/C29M-09 [51]. The cassava was then ground by a mechanical machine, and only particles passing through 75 µm sieves were used in the study. Figure 1 shows the cassava flour used for this study. The elements and morphology of the samples were determined using EDS and SEM analysis (Table 1).

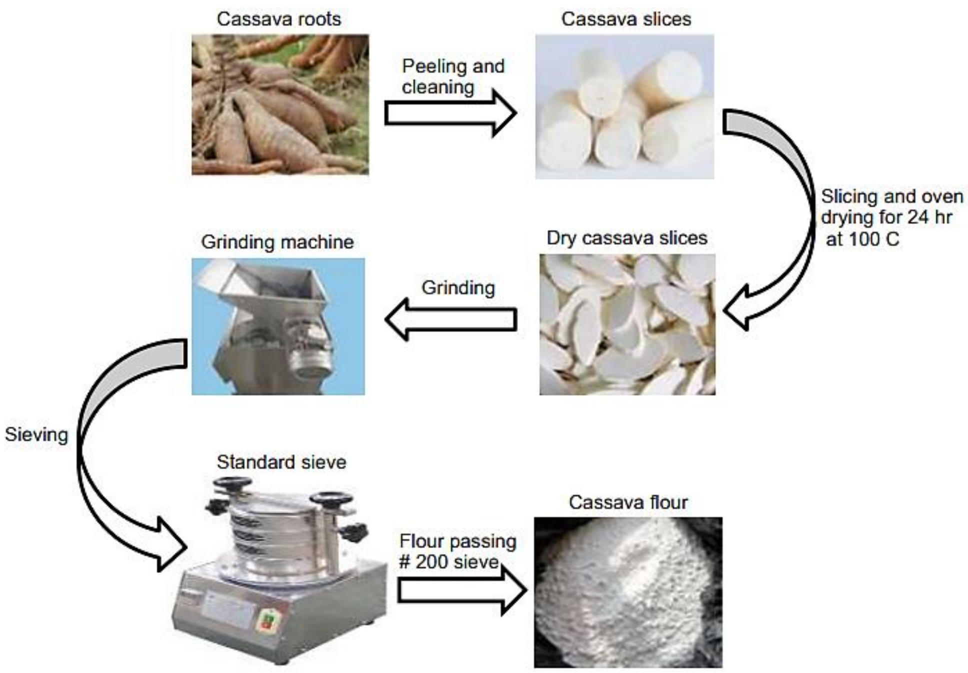


Figure 1. Processing of cassava flour

Table 1. Tests on materials

Material Testing		Physical and hardening tests	
Test Conducted	**Codes**	**Examining**	**Codes**
Sieve Analysis	ASTM C33/C33–18, 2010	Slump	BS 8110-102:1983
ASG	ASTM C128-01	Compacting factor	BS EN 1881-103
Aggregate Water Absorption	ASTM C128-01	Compressive strength	BS EN 1881-03: 1983
Voids in and density Aggregate	ASTM C29-97	Tensile strength	BS EN 1881-03: 1983
Fineness Modulus	ASTM C33/C33–18, 2010	Flexural strength	BS EN 1881-03: 1983
Sieve Analysis (CF)	ASTM D7928-7	Water absorption	ASTM C642
CF and Cement SG	ASTM C 188	Permeable voids	ASTM C642
Setting time	BS EN 196-3	-	-
Soundness	BS EN 193-3	-	-
Consistency	IS 4031-4	-	-

2.1.2. Experimentations

A total of six concrete mixes were prepared. Mix No. 1 was made of 100% cement and was the control mix, denoted CM. The remaining five mixes were prepared by adding cassava flour in percentages of 1, 2, 3, 4, and 5, respectively. These mixes were denoted CF1, CF2, CF3, CF4, and CF5, respectively. A water-cement ratio (w/b) of 0.35 was used for all mixes. A superplasticizer dosage of 0.8% as a percentage by weight of the combined weight of cement and CF was used. Material proportions for all mixes are given in Table 2. A concrete mix design was carried out to ACI 211.4R-08 [52]. X-ray fluorescence (XRF) and x-ray diffraction (XRD) were used to do chemical analysis on both Portland pozzolanic cement and cassava flour. This was done in accordance with BS EN 206:2013 [53].

Table 2. Proportions of concrete mix in kg/m^3

Mix	C.A			F.A	Cement	Water	S.P	C.F
	6.35-12.7	3.18-6.35	1.58-3.18					
CM	405	538	53	530	500	170	4	0
CF1	405	538	53	530	500	170	4.041	5
CF2	405	538	53	530	500	170	4.081	10
CF3	405	538	53	530	500	170	4.121	15
CF4	405	538	53	530	500	170	4.161	20
CF5	405	538	53	530	500	170	4.201	25

2.1.3. Test Methods for Fresh Concrete Properties

Workability tests on fresh concrete were carried out using the slump and compacting factor tests (Figure 2). A further test was carried out to determine the setting time of the concrete. All tests were carried out to BS EN 206:2013 [53].

(a) (b)

Figure 2. Concrete workability (a) 110mm slump for CM. (b) 43mm slump for CF5

2.1.4. Physical State Property Tests

On 100-mm cube samples, compression strength tests were performed. Cylinders of 100 mm in diameter and 200 mm in height were used for the splitting cylinder experiments. Testing for flexural strength was done on 350 mm-long, 100 mm-square cross-sectional, rectangular prisms. A total of 90 cubes, 18 cylinders, and 18 prisms were produced and allowed to cure in water at room temperature. At 3, 7, 28, 56, and 90 days, compression strength tests were conducted. At 28 days, split tensile and flexural strength tests were conducted. For each record, the average of three samples was calculated. According to BS EN 196-3 [54], all tests were performed. According to IS: 4031 (Part4)-1988 [55], research on water absorption, bulk dry density, and porosity void spaces was carried out. Three cylindrical samples, each measuring 100 mm in diameter and 200 mm in height, were manufactured in each case and allowed to cure for 28 days at room temperature in water. Each test required the preparation of 18 cylinders altogether. The samples were oven dried at 100 °C until there was a weight change of less than 0.5%. The samples were then taken out of the oven and allowed to cool for 24 hours in a dry, airtight container. After cooling, each specimen was weighed immediately (W_d). After that, the specimen was put into a container with its longitudinal axis horizontal, and tap water was added until the specimen was covered by 30 mm of water (Figure 3). The sample was taken out after 30 minutes, dried, and weighed (W_w).

(a) Compressive test (b) Splitting test

(c) Flexural test (d) Water Absorption test

Figure 3. Concrete mechanical strength and durability tests

3. Results and Discussions

3.1. Material Characterization

Tests carried out on materials included PSD, SG, BD, WA, VC, and SC for fine aggregates.

3.1.1. Physical and Mechanical Properties of Materials

The physical properties of aggregates, cement, and cassava flour are given in Table 3. In addition, Figure 4 shows the grading results for cassava flour, fine aggregate, and coarse aggregate. The fine aggregate had a fineness modulus of 2.71, which was within the range of 2.3-3.1, a specific gravity of 2.61, and water absorption of 3.86%, not exceeding 4, all of which conformed to ASTM C128-01 [50]. In accordance with the ASTM C33/C33M-18 [48] criteria of not exceeding 5%, the silt percentage of 4.77% for fine aggregate was acceptable. 90% of the coarse aggregate particles in Figure 4 fall in the 5–12.5 mm range. It can be deduced from this that the majority of the aggregate made it past the 10 mm sieve. It is possible to use the envelope curve for high-strength concrete because it is between the upper and lower limit curves, as stated in ASTM C33/C33M-18 [48]. Aggregates bulk densities, 1316 and 1553 kg/m^3, fall between 1200 and 1750 kg/m^3. The results for the chemical analysis of cement and cassava flour are given in Table 4. It is observed that cassava flour contains appreciable amounts of SiO_2, Al_2O_3, and CaO, which can react in the presence of water to produce cementitious hydrated calcium silicates and aluminates, thereby increasing the strength of concrete. Loss on ignition (LOI) for cassava flour was higher than for cement but was within the Tariq et al. (2021) [56] specified range of 12%. The chemical and physical characteristics of the superplasticizer are shown in Table 5. Scanning electron microscope (SEM) imaging is given in Figure 5. More and more definitive results are being offered by scanning electron microscopy.

Table 3. Physical properties of materials

Property	Unit	Coarse A	Fine A	PPC	CF	Limits
Apparent SG	g/cm^3	2.66	2.61	2.86	1.49	
BSG	g/cm^3	2.52	2.34	-		
Fineness Modulus	m^2/kg	-	2.71	300		
SG on Oven dry basis	g/cm^3	-	2.18			
Compacted bulk density	kg/m^3	-	1,677			
LBD	kg/m^3	1,316	1553	-	-	
WA	%	3.50	3.86			
SC	%	-	4.77			
Voids in Loose Aggregate	%	-	28.19			
Moisture Content	%	3.65	3.58			
Maximum Particle Size	mm	12.5	5	-	-	
Residue	32 Mic	-	-	2.66	-	
Specific surface	Cm^2/g	-	-	4016	-	
Standard consistency	%	-	-	31.0	-	
Soundness	mm	-	-	0.5	-	
Initial setting time	Min	-	-	231.6	-	≥ 60
Final setting time	Min	-	-	322.0	-	≤ 350
Compressive strength at 2 Days	MPa	-	-	24.4	-	≥ 10
Compressive strength at 28 Days	MPa	-	-	49.6	-	≥ 62.5
Colour	-		-	Grey	-	-

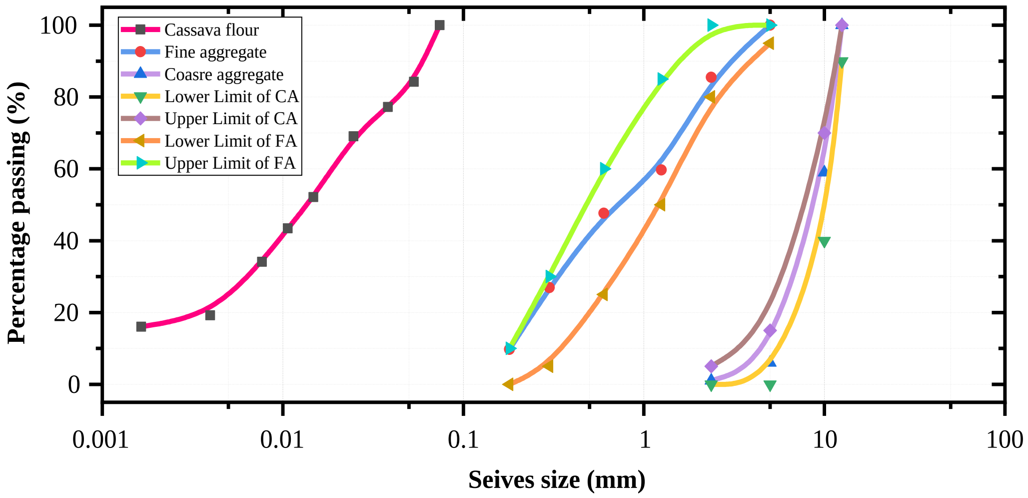


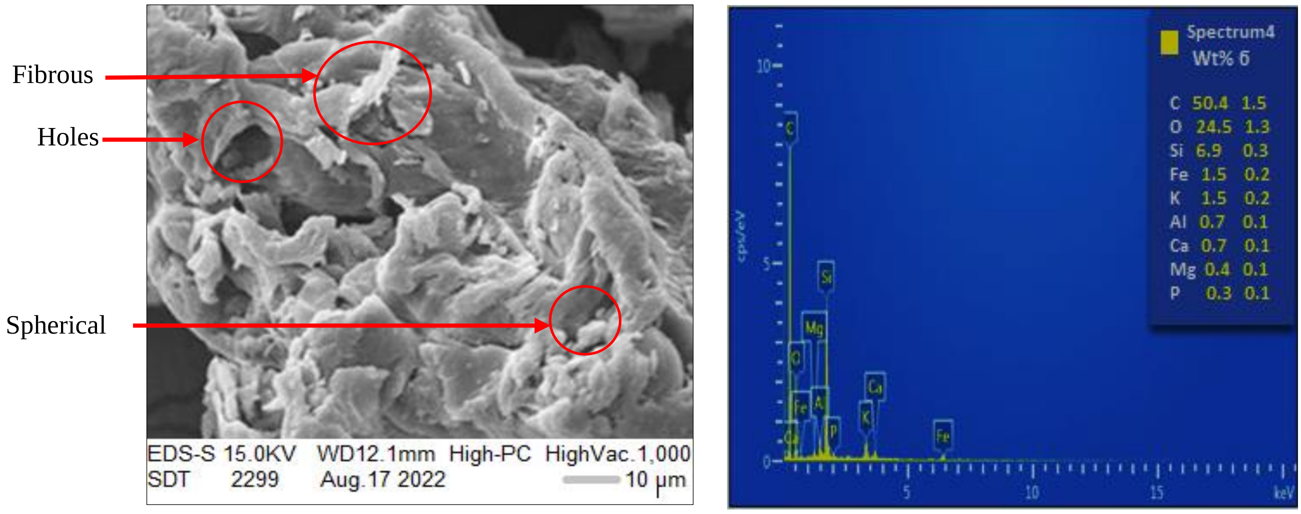
Figure 4. Materials gradient curve (mm)

Table 4. Chemical compositions of CEM II/B-P 42.5 N and cassava flour

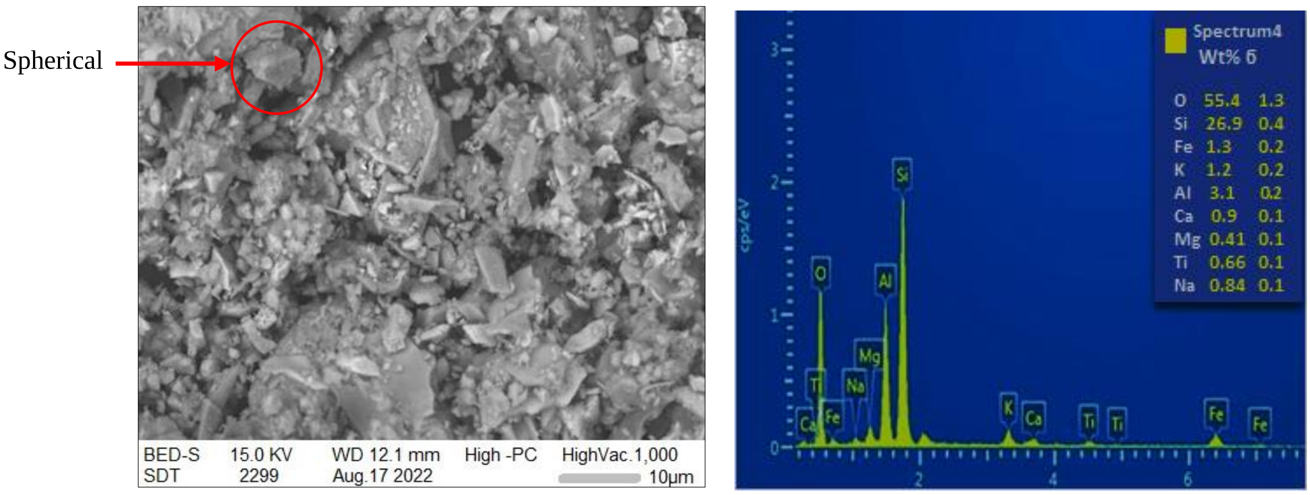
Portland pozzolanic cement (CEM II/B-P 42.5N)				Cassava flour
Compound	**Abbreviation**	**Weight (%)**	**Limits**	**Weight (%)**
Silicon oxide	SiO_2	24.42	-	20.156
Aluminium oxide	Al_2O_3	6.02	-	3.511
Iron oxide	Fe_2O_3	3.75	-	4.34
Calcium oxide	Cao	57.06	> 50	8.280
Potassium oxide	K_2O	8.92	-	3.45
Magnesium oxide	MgO	1.28	-	1.891
Phosphorus pentoxide	P_2O_5	-	-	0.059
Iron	-	-	-	1.975
Sodium Oxide	Na_2O	0.84	-	-
Chloride	CL-	0.01	≤ 0.1	0.001
Insoluble residue	I.R.	12.05	-	-
Pozzolanicity	Pozzolanicity	Pass 35	-	-
Sulfur	SO_3	2.66	≤ 3.5	0.156
Loss of ignition	LOI	4.16	-	6.34

Table 5. Properties of Sika Viscoflow 615 KE

Property	Superplasticizer
Color	Yellowish
Form	liquid
Solid content	34%
Total Chloride Content	Nil
Effect on Setting	Retarding according to dosage
Density (kg/L)	1.08 kg/l (at +20°C) ± 0.05
Chemical Base	The aqueous solution of modified Polycarboxylate
Dosage	0.2 - 2.0% by weight of cement



(a) SEM/EDS analysis of cassava flour



(b) SEM/EDS analysis of PPC

Figure 5. SEM/EDS analysis of cassava flour and Portland pozzolanic cement

A scanning electron microscope (SEM) is a type of electron microscope that can process the signal of each sample using different methods so that it produces images of the sample by scanning the surface with a focused beam of electrons. Electrons interact with the atoms in the sample and produce a different signal that contains information about the surface and components of the sample. Similarly, SEM/EDX is an effective microbeam technology for sample electron analysis. The electron beam is scanned, usually in the form of a point scan and the position of the beam is combined with the intensity of the signal to produce an image. Figure 5 shows microscopic analysis images of cassava flour and cement taken with scanning electron microscopy, which accurately represent the morphology and volume of the particles. In cassava flour, the majority of the particles are porous and have an irregular shape.

Table 6 shows the physical properties of CF when incorporated into cement paste. It is observed that CF increases the setting time of cement paste, and this set retarding effect increases with an increasing percentage of CF added. In all paste mixes, adding cassava flour resulted in higher initial and final setting times than the control paste. The increase in initial setting times varied from 51 minutes for a 1% CF addition to 112 minutes for a 5% CF addition. On the other hand, the final setting times increased by 60 minutes and 188 minutes for the two extremes. However, in all cases, the cement paste complied with BS EN 196-3 [54], which requires that the final setting should not exceed 10 hours. The soundness test was conducted to determine the presence of un-combined lime in cement. The analysis was conducted by BS EN 196-3 [54]. Although there was no change in volume in the entire blended cement, it was observed that soundness increased as the percentage of cassava flour increased. The cassava flour for all the percentage additions conforms to BS EN 196-3 [54] by not exceeding 10 mm. The percentage increase from 0.3% to 1.3% for cassava flour mixes is determined by the cement consistency test, which determines the amount of water required to initiate the chemical reaction (Figures 6 and 7). The consistency test was conducted based on IS: 4031 (Part4)-1988 [55]. The results show an increase in the consistency of the paste of 25.9% at 1% cassava flour addition and 98.2% at 5% cassava flour addition. According to the study by Gupta & Pal (2020) [57] and Singh & Venkatanarayanan (2020) [58] Portland Pozzolanic cement improve the self-compacting of concrete.

Table 6. The physical characteristics of cement paste blended with cassava flour

-	Cassava flour addition (%)					
Physical property	0%	1%	2%	3%	4%	5%
Initial setting time (min)	120	171	182	192	221	232
Final setting time (min)	242	302	319	336	383	430
Soundness (mm)	1.3	1.6	1.7	1.9	2.2	2.6
Consistency (%)	32.8	41.3	46.7	51.1	60.9	65.0

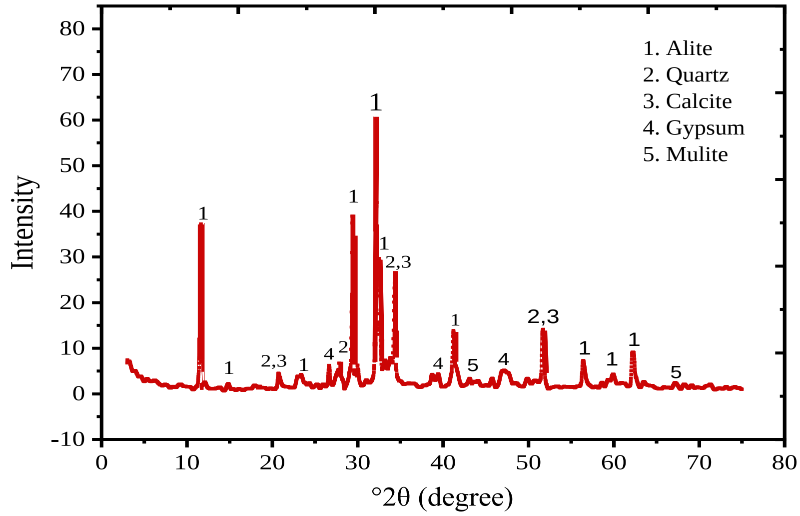


Figure 6. XRD pattern of Portland pozzolanic cement (CEM II/B-P 42.5N)

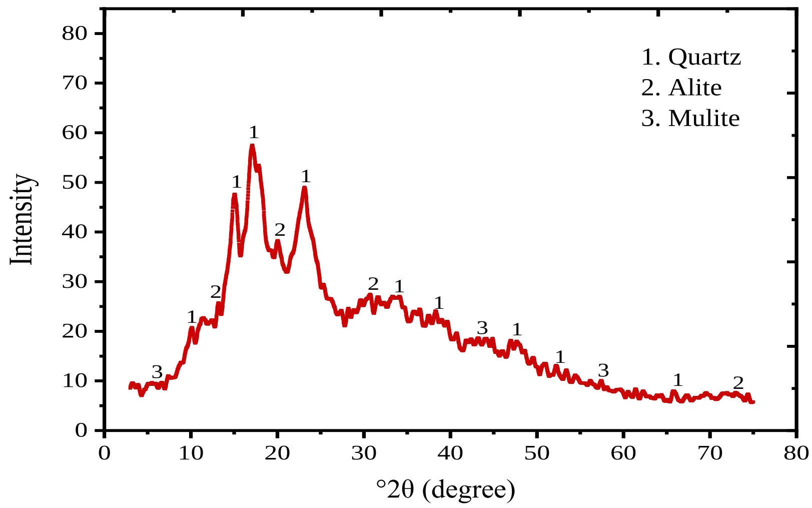


Figure 7. XRD pattern of Cassava flour

3.2. Fresh and Hardened Properties of High-Strength Concrete

Fresh Properties and Slump

With an excess of CF content in the mix, there is a steady decrease in the slump and compacting factor values of concrete. The workability metrics for the cassava flour-infused concrete were significantly higher than those for the control concrete. The enhancement in workability increases along with the dosage level of the admixture. The decrease in workability is an indication of the presence of surface activity in cassava flour. These agents bind to cement particles and negatively charge them, causing them to resist one another and causing particle dispersion and mobility. An increase in workability is also due to the use of ungelatinized starch in concrete. Because of its viscosity characteristics and thickening ability, starch in concrete lowers its workability. The results were in line with the findings of Okafor (2010) [36], and Xavier (2020) [59], but disagreed with Agbi & Uguru (2021) [60], and Oni et al. (2020) [61].

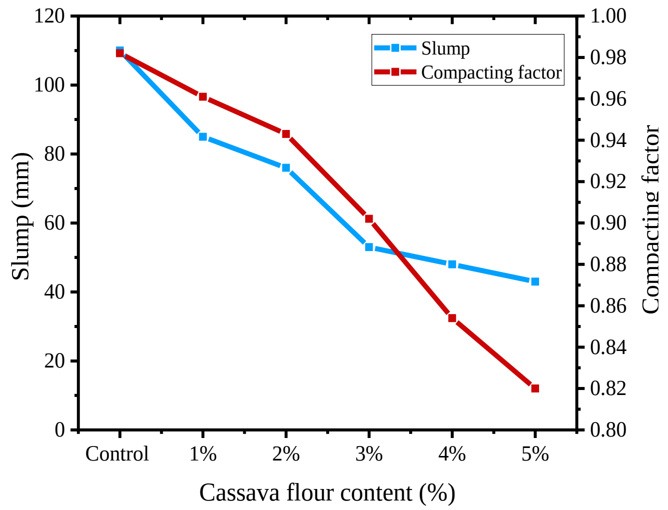


Figure 8. Physical properties of Cassava flour concrete

Hardened Properties of Concrete

The results for compressive strength, splitting cylinder strength, flexural strength, water absorption, porosity (void space), and density of high-strength concrete were as tabled and discussed below (Table 7).

Table 7. The average values of hardened properties for the three replicate samples

	Compressive Strength (MPa)						STS	FS			
S.No.	**3D**	**7D**	**14D**	**28D**	**56D**	**90D**	**28**	**28**	**W (%)**	**V (%)**	**BDD (Kg/m^3)**
0%	55.2	59.1	65.6	67.4	69.4	70.1	3.45	6.36	1.67	14.7	2.4
1%	57.4	63.3	69.8	72.7	75.7	78.7	3.89	6.86	1.62	13.2	2.4
2%	57.9	66.4	72.1	74.4	78.2	80.6	4.03	7.06	1.462	9.2	2.3
3%	58.6	67.2	75.6	77.8	80.6	82.8	4.55	7.37	1.43	8.5	2.2
4%	58.4	66.9	74.4	77.3	80.1	82.1	4.26	7.11	1.397	7.2	2.1
5%	58.1	66.2	73.8	76.9	80.0	81.9	4.22	7.04	1.3	6.8	2.0

Compressive Strength (CS)

Figure 9 displays the compressive strength of the control mix and mixes including cassava flour after 90 days of curing. The compressive strengths for all of the mixtures containing cassava flour were greater than those for the control mixture. It has been reported that mix 3 showed early strength production above the control with incremental increases of 6.16, 13.71, 15.24, 15.43, 16.14, and 18.12 % at 3, 7, 14, 28, 56, and 90 days of curing, respectively. The increase observed up to 90 days of curing can be attributed to concrete having less of a tendency to bleed and segregate as a result of the addition of cassava flour, which enhances the rheology of concrete. Additionally, cassava flour helps concrete by increasing internal curing, the degree of hydration, and preventing the creation of unfavourable hydration products like ettringite. The greater workability and improved degree of compaction obtained by adding cassava flour to concrete are related to the higher strength demonstrated by the concrete-containing additive after an age of around 7 days due to the direct correlation between degree of compaction and strength. The SiO_2, Al_2O_3, and CaO in cassava flour contribute to the creation of more cementing C-S-H and C-A-H, which accounts for the stronger mixes made with it. The gel produced from the interaction of cassava flour with water easily covers the surfaces of the cement granules due to the particle size, shape, and surface area. It can make the concrete mixture more cohesive and increase its compressive strength. According to Xavier (2020)[59], the dispersion of cement particles and the production of a denser gel as a result of delayed setting may also have an impact on the improved compressive strength development. This finding is consistent with what other studies have discovered. Age-related gains in strength have been seen, for instance, by Okafor (2010) [36]. Similar findings were found by Ikoko et al., 2021 [41], Xavier (2020) [59], Kone et al. (2022) [34], and Oluwabusayo Oni et al., (2020) [25]. Since it can make concrete stronger when it's pressed, cassava flour could be thought of as a green material additive.

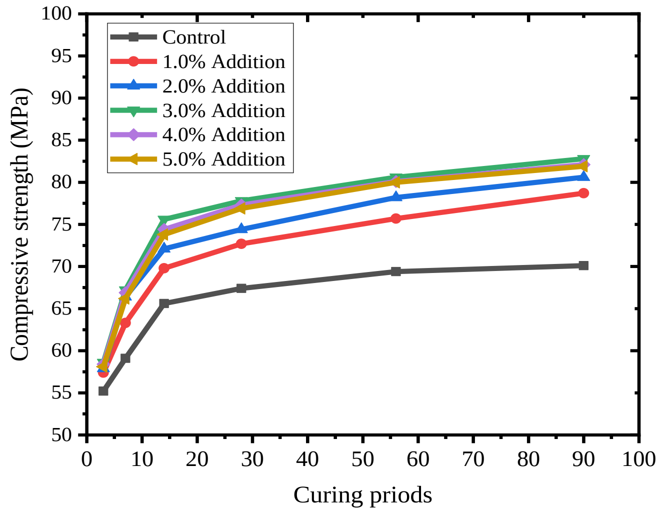


Figure 9. Effect of the cassava flour on compressive strength of concrete

Splitting Cylinders Strength (SCS)

The split tensile strength of the concrete is demonstrated in Figure 10 over 28 days of water curing. The mixtures containing cassava flour are stronger than the control mix in terms of compressive strength. The 3% cassava content resulted in the strongest strength gain of 31.88%. In comparison to other mixes, those containing 1, 2, 4, and 5% cassava flour demonstrated 12.74, 16.85, 23.48, and 22.32%, which were all greater than the control mix. In a similar study, by Oni et al. (2020) [61] said that the use of cassava starch has reduced the microcracks in concrete by making the aggregate and cement stronger. This has increased the split-tensile strength of the concrete.

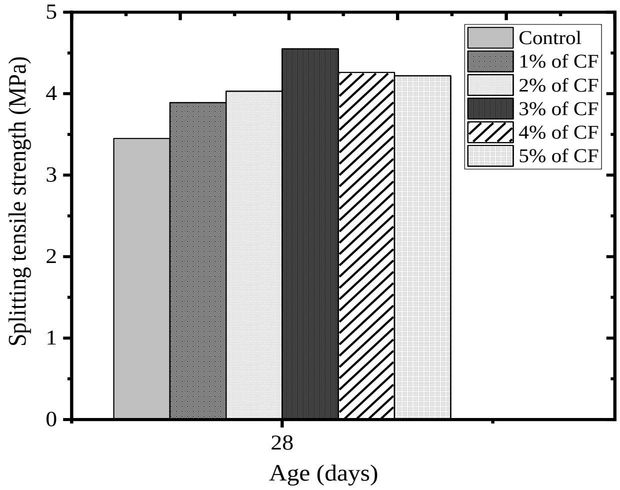


Figure 10. Effect of Cassava flour on splitting tensile strength of concrete

Flexural Strength (FS)

The flexural strength of the mixes at 28 days is shown in Figure 11. With higher strengths than the control obtained by all mixes with cassava flour, the strengths follow the same pattern as for compressive and splitting tensile strengths. The mixture with 3% cassava showed the greatest improvement in strength above the control mixture, with a gain of 15.78%. This is because cassava flour prevents the formation of micro-cracks in the interphase of the aggregate and cement paste, so it can increase flexural strength. In that proportion the mixtures containing 1, 2, 4, and

5% of cassava flour displayed 7.84, 11.05, 11.72, and 10.67%, respectively, and were greater than the control. Similarly, discovered in a study conducted by Oni et al. 2020 [61] and Herring et al. (2022) [13]. The use of Portland pozzolanic cement in concrete can also improve flexural strength because PPC contains between 20 - 30 % natural pozzolana, which can improve concrete strength over time, as reported by Okumu (2018) [16] and Marar et al. (2011) [62].

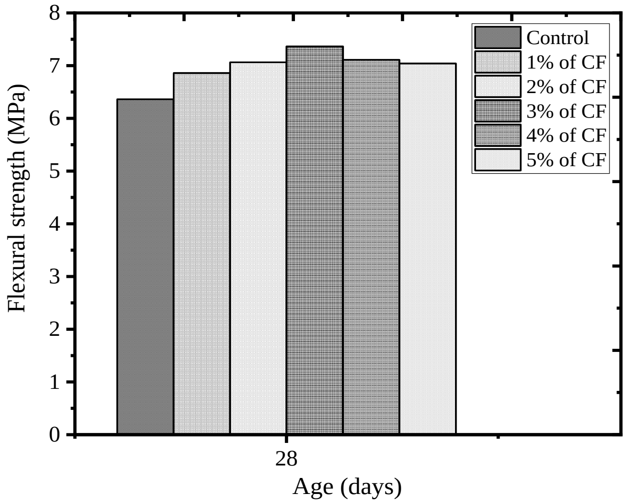


Figure 11. Effect of Cassava flexural strength on concrete

Water Absorption

The water absorption findings for the five combinations are shown in Figure 12. Water absorption decreases as cassava flour content increases. At a 1% addition of cassava flour, the water absorption falls by 11.3%, and at a 5% addition, it reaches a high of 60.58%. Cassava flour has a pore-filling effect, as seen by the drop in water absorption percentages at all degrees of cassava flour addition. The hydration of the cassava flour is responsible for producing the cementitious calcium silicate and alumina that were added. Oni et al. (2020) [61] reported that the use of cassava starch has reduced the number of microcracks in concrete by improving the bonding between the aggregate and cement paste, leading to a lower percentage of water absorption. On the other hand, according to a different study by Agbi & Uguru (2021) [60], the decrease in water absorption could be explained by the fact that the cassava starch solution tends to reduce the void ratio in the concrete blocks and form an impermeable coating around the paper pulp, reducing the concrete block's capacity to absorb moisture from the environment. Equation 1 was used to calculate the percentage of water absorption.

$$\text{Percentage of absorption} = \frac{W_w - W_d}{W_d} \times 100 \tag{1}$$

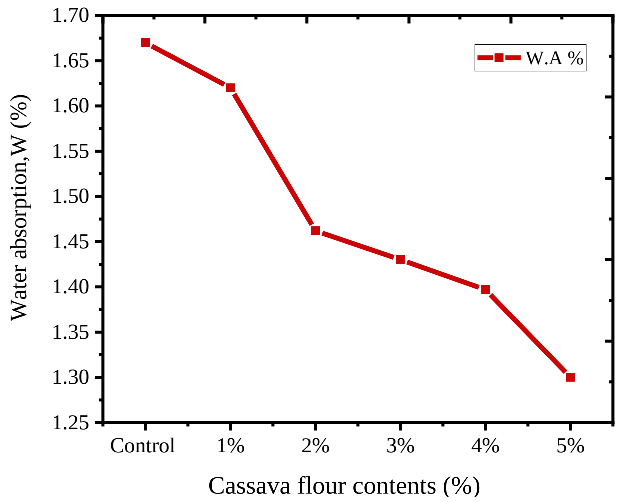


Figure 12. Water absorption of concrete blended cassava flour

Bulk Dry Density (BDD) of Hardened Concrete

Figure 13 shows the effect of cassava flour on the BDD of the hardened concrete after 28 days of water curing. For 1% cassava flour addition, there is no change in BDD, but after that, there is a progressive reduction in BDD with increasing cassava flour content. The reduction in BDD ranges from 4.2% at 2% cassava flour addition to 16.7% at 5% cassava flour addition. Because cassava flour has a lower specific gravity than cement, the BDD has decreased. But it is important to note that the BDD values still fall within the range of 2,000 to 2,600 kg/m^3, which BS EN 206 (2014) [53] says is normal for concrete.

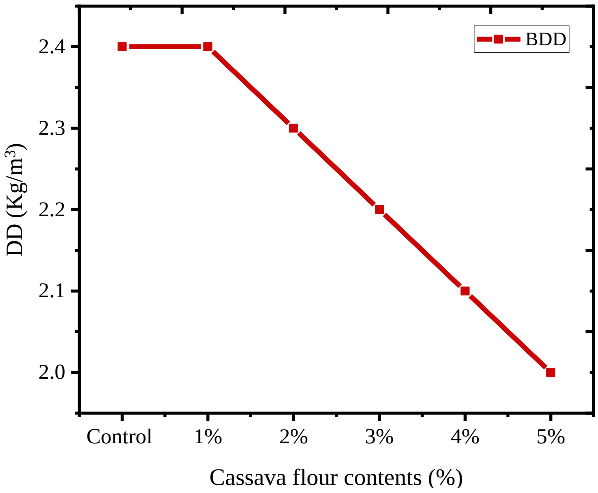


Figure 13. Density of hardened cassava flour concrete

Porosity Void Space Volume in Cassava Flour Concrete

The effect of cassava flour on the void spaces in cassava flour concrete after 28 days of water curing is shown in Figure 14. The volume of voids decreased appreciably with an increase in cassava flour content. At 1% cassava flour addition, a 10.2% drop in the volume of voids was achieved, and the percentage reduction in voids increased progressively to 53.7% at 5% cassava flour content. This confirms the densifying effect of cassava flour, which can be attributed to the addition of cementitious gel produced by the hydration of the cassava flour.

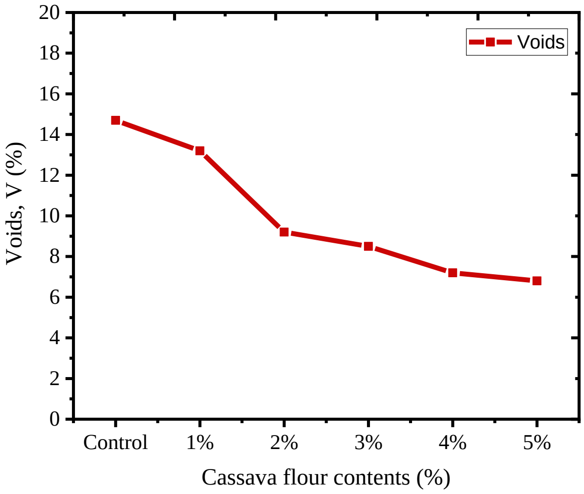


Figure 14. Porosity void spaces in cassava flour concrete

4. Conclusion and Recommendation

This study demonstrates that it is possible to decipher characteristics of cassava flour and Portland pozzolanic cement using SEM/EDS and XRD tests combined with image analysis-based methodology. The combination of shape parameters maximized the understanding of morphological, shape characteristics, and chemical compositions. The usage of SEM and XRD analysis demonstrated herein could support further studies intended for the identification of the physical properties and chemical compounds of materials. Researchers have investigated the physical properties of concrete (slump and compacting factor, initial and final setting time, soundness, and consistency), mechanical properties (compressive strength, splitting tensile strength, flexural strength, bulk dry density, and porosity void space volume), and durability properties of concrete (water absorption) made with Portland pozzolanic cement CEM II/B-P blended with cassava flour in the range of 1% to 5% by weight of cement and compared to the control mix. Concrete was cast using a percentage of cassava flour as an additive to the concrete mixture to produce high-strength concrete. It was found that cassava flour had the effect of thickening the paste of fresh concrete, resulting in a reduction in the concrete's workability. On the other hand, initial and final setting times, soundness, and consistency were increased. These factors increased with the increase in cassava flour content. In hardened concrete, it was found that cassava flour increases the strength of concrete in compression, splitting cylinder tensile strength and flexural strength. It was found that high early strength is obtained at 3–28 days with cassava flour additions of up to 3% and a water-cement ratio of 0.35, with potential for early striking of formwork and fast construction. At 28 days of age, compressive strength, split tensile strength, and flexural strength followed the same trend. In addition, water absorption, dry density, and porosity of the concrete were all reduced with the increased cassava flour content. Therefore, cassava flour can be optimally used as an admixture at a 3% addition by weight of Portland pozzolanic cement in concrete based on its ability to modify the physical, mechanical, and durability properties of concrete.

The authors recommend that cassava flour can be used as an additive material in concrete mixes at different dosages up to 3% to produce high-strength concrete and give concrete benefits such as enhanced strength, decreased weight, decreased void volume, and decreased water absorption. Adding cassava flour to concrete as an admixture encourages the use of locally alternatives materials in building construction and addresses the cost and availability of chemical admixtures in developing countries. The use of Portland pozzolanic cement with cassava flour to produce high-strength concrete rather than ordinary Portland cement helps to reduce the depletion of natural resources such as limestone, which is used in the clinker process, and harmful carbon dioxide emissions, as well as global warming concerns. Also, CEM II/B-P 42.5 has high early strength due to the amount of natural pozzolana blended into the cement. In developing countries, a new industry based on processing cassava roots for use in concrete could lead to more jobs and better economic activity.

5. Declarations

5.1. Author Contributions

Conceptualization, M.G.O.A.; methodology, M.G.O.A.; validation, M.G.O.A.; formal analysis, M.G.O.A.; investigation, M.G.O.A.; resources, M.G.O.A.; writing—original draft preparation, M.G.O.A., and J.N.T.; writing—review and editing, J.N.T., and M.M.; visualization, D.O.K.; supervision, J.N.T., and M.M. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding and Acknowledgements

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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