Comparative Effects of Cassava Starch and Simple Sugar in Cement Mortar and Concrete

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Abstract

Comparative effects of simple laboratory quality sugar and cassava starch on grade C35 concrete were studied in the laboratory. The simple white sugar was used at concentrations of 0 to 1% by weight of cement in concrete cured at 3, 7, 14 and 28 days using ordinary Portland cement. Cassava starch of the same concentration by weight of cement was used in concrete. The compressive strength results showed some marginal strength gains at all ages but peaks at 11.84% at 3 days at 0.05% sugar concentration. The maximum short term strength gain for cassava starch is 22.60% at 3 days at 0.1% starch concentration; and like the case of sugar this short term strength gain was not sustained at 28 days. At 28 days, there was a maximum strength increase of 7.80% with 0.05% cassava starch concentration. For simple sugar the maximum strength increase at 28 days was 3.62% at sugar concentration of 0.06%.

Keywords: Cassava starch, sugar, compressive strength, concrete.

Introduction

A delay in the setting of cement paste can be achieved by adding a retarder to the concrete mix. Retarders generally slow down the hardening of the cement paste by stopping the rapid set shown by tricalcium aluminate but do not alter the composition of hydration products (Lea, 1988; & Neville, 2006). The delay in setting of the cement paste can be exploited to produce architectural finish of exposed coarse aggregate (Neville, 2006). Sugar, carbohydrate derivatives and some salts exhibit retarding action (Lea, 1988; Neville, 2006; & Ramachandran, 1993). Sugar belongs to the type of retarders that can hold up setting and hardening of cement paste indefinitely (Lea, 1988). It is believed that retarders modify crystal growth or morphology, becoming absorbed on rapidly formed membrane of hydrated cement and slowing down the growth of calcium hydroxide nuclSei thus forming a more efficient barrier to further hydration than is the case without a retarder (Neville, 2006). The retarder is believed to be finally removed from solution by being incorporated into the hydrated material without necessarily forming different complex hydrates (Young, 1972). Retarders can be useful when concreting in hot weather, when the normal setting time of concrete is shortened by the higher ambient temperature. Sugar is used in producing retarders (Shetty, 2004). Commercial lignosulfonates used in admixture formulations are predominantly calcium-sodium based with sugar content of 1-30% (Rixom & Mailvaganam, 2007). Molasses (sugar) as a retarder has been used in the England-France channel construction in the early 1990s to prevent the setting of residual concrete since washing out underground was not possible (Neville, 2006). However, hardened Portland cement concrete without special treatment has been known to be attacked by sugar solutions. Light refined molasses are reported to have a more aggressive action than dark molasses on hardened concrete (Lea, 1988). Work on molasses in concrete at concentrations of 0.2%, 0.4%, and 0.7% at 1, 3, and 7 days showed slight increase in concrete strength at all ages with no adverse effect over long time periods of up to 900 days (Jumadurdiyev, *et al*. 2005). The sugar used in this work is simple laboratory sucrose crystals ($C_{12}H_{22}O_{11}$) with the specifications in Table 1. Sugar has been observed to increase the surface area, alter rate of hydration and the pore size distribution of cement paste; increased curing temperature of OPC mortar containing 1% sugar has been reported to have very quick hydration (Garci Juenger & Jennings, 2002).

Table 1: Composition of simple laboratory sugar.

Water insoluble Matter	Loss on drying	Sulphate Ash	Nitrogen Compound	Cadium (Cd)	Iron (Fe)	Nitrate (N)	Chlorine (Cl)	Sulphate (SO_4)	Copper (Cu)	Lead (Pb)	Zinc (Zn)
0.003%	0.5%	0.005%	0.002%	0.000005%	0.00001%	0.00005%	0.0005%	0.002%	0.001%	0%	0.00001%

Cassava starch is a white powder with no smell or taste and is a carbohydrate that is classified as complex sugar with high molecular mass (Frankhauser, *et al.* 1989), with molecular formula $(C_6H_{10}O_5)_n$ and a density of 1.5g/cm^3 (Wikipedia). Cassava starch is a carbohydrate polymer, composed of two molecular components: linear amylose and branched amylopectin. They are organized in alternating crystalline and amorphous lamellae in the granules, with heterogeneous granule size varied from less than 100 nm (nanoparticles) to a few mm (microparticles) (Szymońska, *et al.* 2008). Cassava starch typically would have the composition given in table 2 (Leonel, *et al.* 2009).

Table 2: Composition of cassava starch.

Moisture	Starch	Fibre	Total sugar	Lipid	Proteins	Ash
12.2%	88.43%	0.15%	0.14%	0.26%	0.07%	0.1%

Source: Leonel, *et al.* (2009)

Cassava production in Nigeria is arguably the highest worldwide with production figure of 34million tonnes in 2002 (FAO), the North Central zone of Nigeria accounting for 7.4million tonnes; representing 0.72tonnes/person and 5% of this is generated as high quality starch for industrial use (Philips et al., 2004). The projected production figure is far above 40million tones. Cassava starch is either extracted from the slurry of grated fresh cassava tubers or from milling peeled dry cassava tubers that are usually grown by small farmers and farming co-operatives that are spread throughout the country.

Materials and Method

Sugar crystals were weighed and dissolved in weighed water before mixing at concentration of 0, 0.05, 0.06, 0.08, 0.10, 0.20, 0.40, 0.60, 0.80, and 1% by weight of cement. The materials were batched by weight and mixed manually. Three concrete cubes were cast for each parameter using simple sugar. The mix proportion of concrete materials used for the study of simple sugar in concrete is given in Table 3.

Table 3: Proportion of concrete mix containing simple sugar.

Cement content	Sand	Coarse aggregates	Free w/c ratio
404.94kg/m^3	645.93kg/m^3	1,340.99kg/m^3	0.42

The sand used is natural river bed quartzite with specific gravity of 2.51 and the coarse aggregate is crushed granite with specific gravity of 2.68 with maximum size of 20mm. The particle size distribution of the sand and coarse aggregates are given in figure 1.

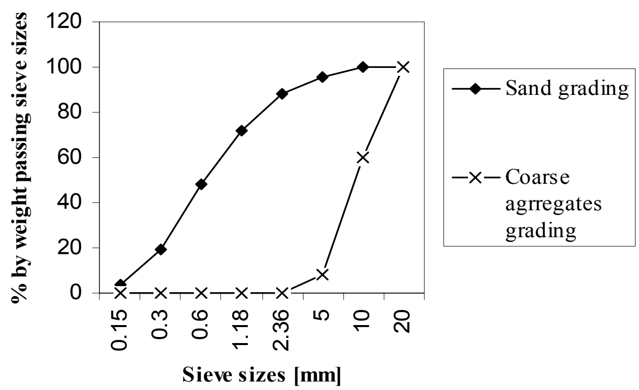

Figure1. Particle size distribution of aggregates for concrete mix containing simple sugar.

The cassava starch used was extracted from cassava milk obtained from a manual press, built for processing cassava slurry into *gari* which is a staple food in Nigeria. Peeled and washed fresh cassava tubers are grated into a slurry that are then put in bags subjected to jacking pressure using local purpose-built mechanical press to expel water. The collected unfermented cassava-water extract i.e. cassava milk, from the press was then allowed to sediment for twenty four hours and the clear water was decanted. The resulting white starch was then dried at room temperature to a moisture content of 16.7%, with a specific gravity of 1.4.

Weighed quantity of the cassava starch dissolved in weighed water at room temperature at concentrations by weight of cement of 0, 0.05, 0.06, 0.08, 0.10, 0.20, 0.40, 0.60, 0.80, and 1% was used in the concrete production. Fresh concrete properties of slump and compaction factor were determined in compliance with standard specifications (B.S. 1881: Part 102, 1983; B.S. 1881: Part 103, 1993).

The concrete was manually mixed and compacted in compliance with standard specifications (B.S. 1881, part 108, 1996). After 24 hours in 150mm steel moulds, the concrete cubes were de-moulded and cured in water for 3,7,14 and 28 days at 21^{o}C in compliance with standard requirements (B.S. 1881 Part 111, 1997; B.S. 12390-2, 2003). After curing, the cube surfaces were cleaned of excess water and crushed using universal compression machine. Ten concrete cubes were cast for each parameter investigated using cassava starch. The proportion of concrete materials used for the cassava starch investigation is given in Table 4.

Table 4: Proportion of concrete mix containing cassava starch.

Cement content	Sand	Coarse aggregates	Free w/c ratio
360kg/m^3	581.33kg/m^3	1,206.87kg/m^3	0.42

The aggregates used were sampled and sieved in compliance with standard requirements (B.S. 8812-101:84; 2002; B.S. 8812-103:1, 2002). The sand used was natural river bed quartzite with specific gravity of 2.65 having un-compacted and compacted bulk densities of 1,591kg/m^3 and 1,690kg/m^3 (B.S.882, 2002).

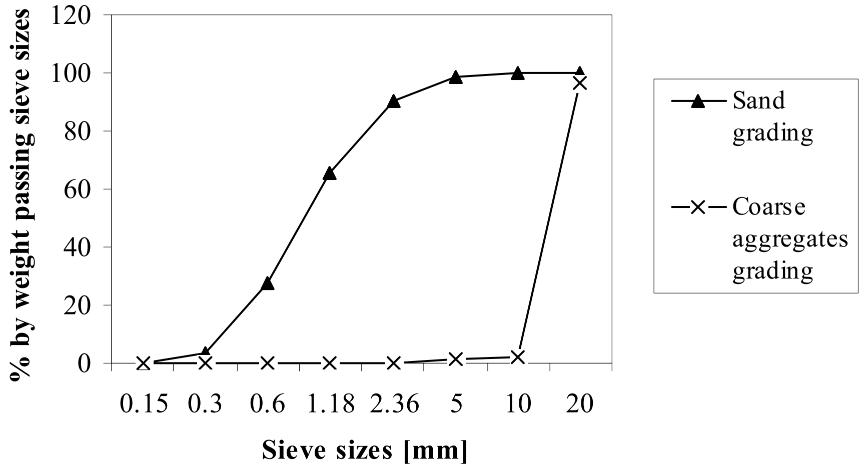

Figure 2. Particle size distribution of aggregates for concrete mix containing cassava starch.

The coarse aggregate used was crushed granite with specific gravity of 2.5 and un-compacted and compacted bulk densities of 1,436kg/m^3 and 1,608kg/m^3 with maximum particle size of 20mm. The results of sieving of the sand and coarse aggregates as percentage by weight passing sieve sizes are given in figure 2. The OPC (B.S. ENV 197-1, 1992) used is a commercial brand with the composition determined by X-ray florescence given in Table 5.

Table 5: Composition OPC.

SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**
24.79%	6.35%	0.92%	58.50%	2.87%	4.91%	0.80%
Na_2O	**Mn_2O_3**	**P_2O_5**	**TiO_2**	**Cl-**	**LSF**	**SR**
0.65%	0.0%	0.15%	0.06%	0%	69.15	3.41
AR						
6.88						

LSF: Lime saturation factor; SR: Silica ratio= $SiO_2/(Al_2O_3+Fe_2O_3)$; AR: Alumina ratio= Al_2O_3/Fe_2O_3

Results and discussion

Effects on cement mortar

The tests on properties of cement mortar were done using the Vicat apparatus (B.S. EN 196-3: 1987). The recorded water content of the OPC mortar of standard consistence was 33%. The effects of sugar and cassava starch on setting times of cement mortar of standard consistence are shown in figures 3 and 4. Figure 3 shows that initial and final setting times increase with sugar content increase and reaches a maximum value at 0.05% sugar content. Continuous decreases of initial and final setting times were recorded at sugar concentrations of 0.08% and above.

Figure 4 shows the effect of cassava starch on initial setting time of cement mortar at standard consistence. There is no noticeable peak, but a general gradual reduction in initial setting time of cement mortar.

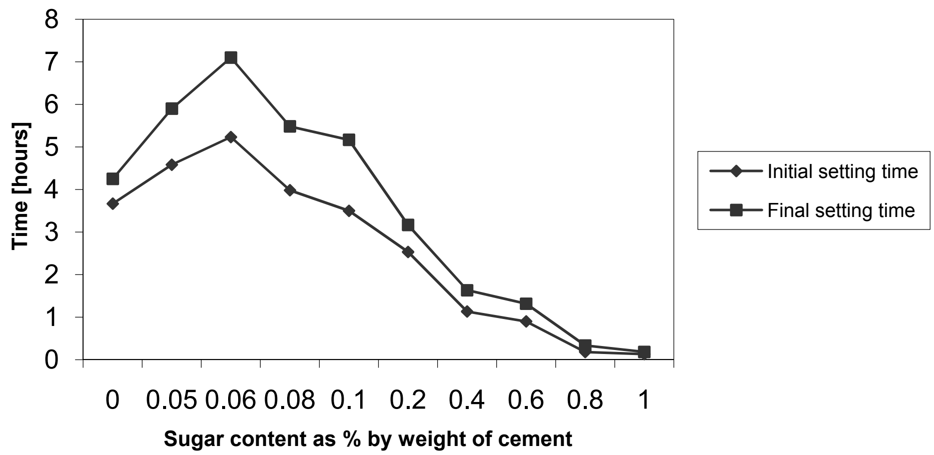

Figure 3. Effect of sugar on setting time of cement mortar.

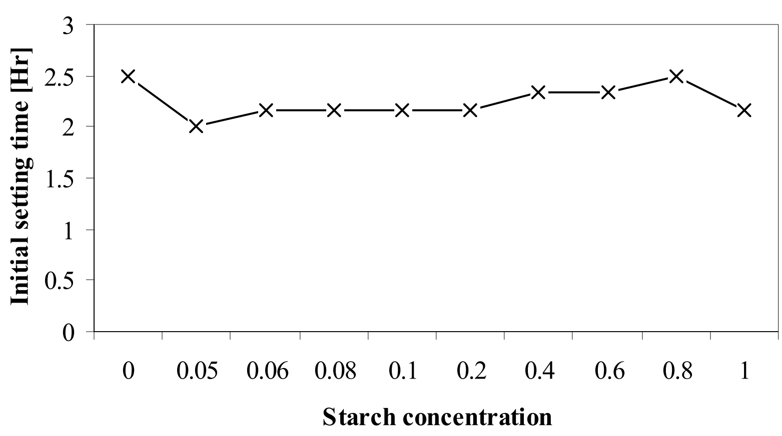

Figure 4. Effect of cassava starch on setting time of cement mortar.

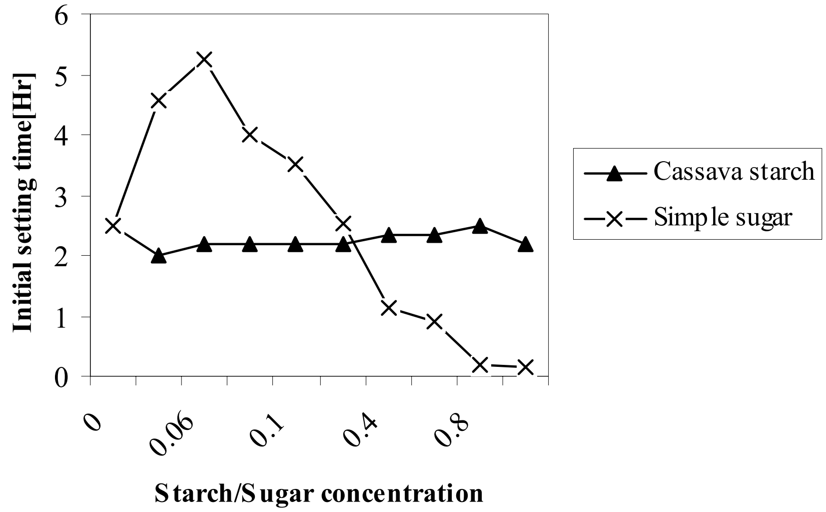

Figure 5. Effects of cassava starch and sugar on initial setting time of cement mortar.

Figure 5 shows the effect of cassava starch and sugar on initial setting times of OPC mortar. Sugar shows a more marked effect on initial setting time of cement mortar compared to cassava starch, decrease in initial setting time below that of the OPC started at 0.4% sugar concentration; sugar produced flash setting from 0.2% concentration. The initial setting times of cement paste containing 0.8% to 1% sugar were recorded in just minutes. Cement mortar with sugar content from 0.6% and above have values of initial setting time below the minimum time of 60 minutes requirement prescribed by ENV 197-1: 1992 for cements with strength up to 42.5MPa (B.S. ENV 197-1).

Effects on properties of fresh concrete

The effects of starch and sugar on properties of fresh concrete are shown in Tables 6 and 7 and in figures 6 and 7. Properties of fresh concrete measured are slump and compaction factor. The compaction factor values for fresh concrete containing both cassava starch and sugar show some scatter and the values are erratic.

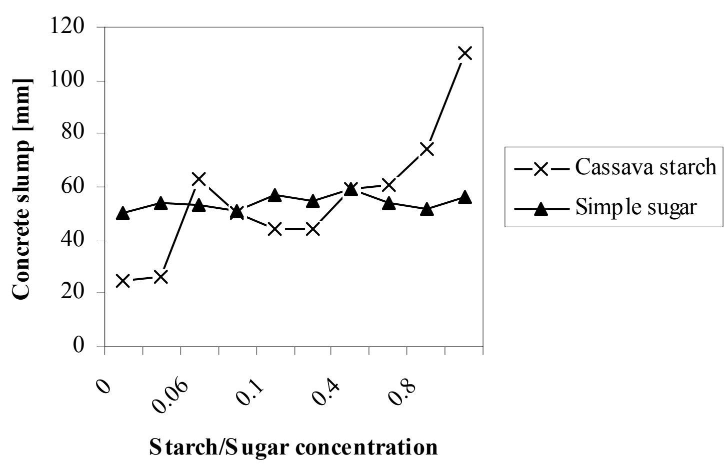

Figure 6. Effect of cassava starch and sugar on slump of fresh concrete.

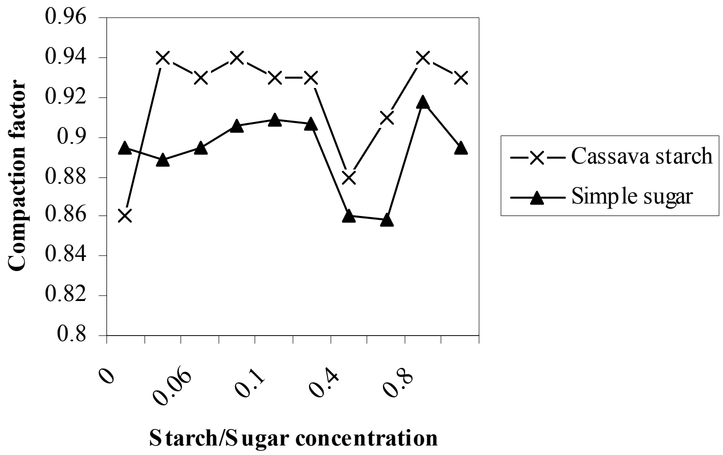

Figure 7. Effects of cassava starch and sugar on compaction factor of fresh concrete.

It does appear that the compaction factor test may not be sensitive enough in measuring the effect of these additives in concrete; compaction factor test is known to have sensitivity that depends on water content (Neville, 2006). Figure 6 shows the effect of sugar on slump of fresh concrete to be constant when compared to that of cassava starch that shows a general increase in slump as the starch concentration increases but with considerable scatter. Starch does appear to cause a linear increase in concrete slump with increase in starch content that could have some advantage in concreting.

The effects of starch and sugar on compaction factor of fresh concrete appear similar as seen in Figure 7; a pattern of general increase in compaction factor up to 0.2% concentration and a dip from 0.4% to 0.8% concentration for sugar, however these values are small.

Effects on compressive strength of concrete

Effects of starch and sugar on compressive strength of concrete cubes at different hydration periods are shown in Tables 6 and 7. From Table 6, compressive strength reduction of concrete cubes starts at 0.06% starch concentration at 28 days. Compressive strength values in Table 7 show that strength reduction of concrete cubes containing sugar starts at of 0.08% sugar concentration at 14 and 28 days. Compressive strength reduction at 28 days starts at 0.06% starch concentration and 0.08% sugar concentration.

At sugar concentration from 0.4% to 1% no compressive strength values were recorded at 3 and 7 days. These levels of sugar concentration in cement mortar had initiated flash setting in mortar as shown in figure 3; this flash setting not result in compressive strength development at early days. These levels of sugar concentrations appear to have resulted in arresting the formation of calcium silicate hydrates (CSH) that is mainly responsible for concrete strength at these earlier days. This effect was not however recorded for cassava starch. Increase in initial setting time at 0.05% and 0.06% sugar concentration resulted in strength increases at 7,14, and 28 days.

Table 6: Effects of cassava starch on physical properties of concrete.

Cassava starch content as% of weight of cement	Initial setting time (hrs)	Slump (mm)	Compaction factor	Average compressive strength (N/mm^2)†			
				3 days	**7 days**	**14 days**	**28 days**
0	2.5	25	0.86	19.34	20.28	29.72	39.51
0.05	2.0	26	0.94	18.58	22.39	29.13	42.59
0.06	2.17	63	0.93	18.38	22.46	29.45	36.96
0.08	2.17	50	0.94	17.52	24.07	29.55	37.55
0.1	2.17	44	0.93	23.71	25.00	29.57	37.06
0.2	2.17	44	0.93	18.05	22.53	29.97	37.30
0.4	2.33	59	0.88	18.68	23.26	31.63	37.14
0.6	2.33	61	0.91	18.13	22.34	31.71	36.64
0.8	2.50	74	0.94	18.07	22.33	27.20	36.53
1	2.17	110	0.93	18.59	22.13	33.38	36.42

† Average values for n=10 cubes.

Table 7: Effect of simple sugar on physical properties of concrete.

Sugar content as % of weight of cement	Initial setting time (hrs)	Slump (mm)	Compaction factor	Average compressive strength (N/mm^2)†			
				3 days	**7 days**	**14 days**	**28 days**
0	2.5	50	0.90	16.05	26.62	36.44	40.88
0.05	4.58	54	0.89	17.95	26.07	36.60	41.99
0.06	5.23	53	0.90	14.62	26.94	37.12	42.36
0.08	3.98	51	0.91	16.57	27.03	34.51	38.88
0.1	3.50	57	0.91	16.39	26.21	31.32	35.43
0.2	2.53	55	0.91	12.82	20.05	25.03	32.64
0.4	1.33	59	0.86	0.00	0.00	20.17	32.08
0.6	0.90	54	0.86	0.00	0.00	3.00	31.47
0.8	0.18	52	0.92	0.00	0.00	2.20	30.66
1	0.13	56	0.90	0.00	0.00	1.07	17.4

† Average values for n=3 cubes.

Conclusion

Cassava starch and sugar exhibit similar effects in concrete at concentrations reported in this study and though their effects on compressive strength of concrete at hydration periods less than 28 days appear inconclusive, there is the need to carry out further studies on their long term effects on concrete. Cassava starch does appear to have beneficial effect of significantly effecting concrete slump increase at concentration from 0.06% though at the cost of strength decrease. This could be particularly relevant in working stiff concrete mixes of low slump. Maximum compressive strength recorded for cassava starch at 28 days occurs at 0.05% concentration with a slightly reduced initial setting time. The maximum compressive strength increase for sugar at 28 days occurs at 0.06% concentration with an increase in initial setting time. Within the range of cassava starch concentration presented in this work, it could serve as a good substitute for sugar as an admixture in concrete.

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