The Impact of Sugar on Setting -Time of Ordinary Portland Cement (OPC) Paste and Compressive Strength of Concrete

[a]Usman, N. D.; [a]Chom, H. A.; [a]Salisu, C.; [b]Abubakar, H. O. ,[b]Gyang, J. B.
[a]Department of Building, School of Environmental Sciences, Modibbo Adama University of Technology, Yola, Adamawa State, Nigeria
[b]Department of Building, School of Environmental Technology, Federal Polytechnic, Nasarawa, Nasarawa State, Nigeria
Correspondence email: napodanusman@yahoo.com

Abstract

Construction activities are accomplished through laid down procedures and parameters such as temperature and humidity. Concreting in hot weather above 100°F accelerates the early hydration of cement and produce concrete with high strength at early ages but later, the strength is reduced considerably. The rapid evaporation of water causes plastic shrinkage in concrete and subsequent cooling cause tensile stresses and cracking. The study seeks to investigate the impact of sugar on setting -time of ordinary Portland cement (OPC) paste and compressive strength of concrete. Sugar used for the experiment was sucrose crystals ($C_{12}H_{22}O_{11}$); it was dissolved in required amount of water. The sugar was used at concentrations of 0, 0.05, 0.06, 0.08, 0.10, 0.20, 0.40, 0.60, 0.80, and 1% by weight of cement. In addition, the compressive strength of the concrete was investigated at 3, 7 and 21 days. Sugar crystals ($C_{12}H_{22}O_{11}$) were weighed and dissolved in the required 0.6 volume of water before mixing. The materials were batched by weight and mixed manually. The increases in initial and final setting times were apparent to sugar content of 0.06%. Reduction in setting times begins from 0.08% sugar content and flash setting occurs from 0.2% to 1%. There was no correlation between the speed of setting of cement paste and strength gain from sugar level of 0.08 to 1%. Strength gain peaks at 0.05% sugar content at 3 days and at 0.06% sugar content at 7, and 28 days respectively. Sugar delays the setting time of cement by up to 1.33 hours at dosage level of 0.06% by weight of cement. No effect on workability, compaction by the use of sugar as admixture in concrete. Higher long-term compressive strength can be achieved in concrete by the use of sugar as admixture. The study recommends that sugar should be used as a retarder but when it is used in excessive amount it reverse its property. The quantity of the sugar and other related quantities must be adequately metered in the production process.

Keywords: Concrete, Compressive Strength, Ordinary Portland Cement, Sugar and Setting-Time

INTRODUCTION

Construction activities are accomplished through laid down procedures and parameters such as temperature and humidity. In practice, desired quality may not be achieved except the exact set of procedures are carefully followed. Concreting in hot weather above 100°F accelerates the early hydration of cement and produce concrete with high strength at early ages but later, the strength is reduced considerably. The rapid evaporation of water causes plastic shrinkage in concrete and subsequent cooling cause tensile stresses and cracking (Neville and Brooks, 2006; Usman, Idusuyi, Emeso, and Simon, 2012).

Similarly, concreting in cold weather is also detrimental. If water in plastic concrete sets, the volume of concrete increases. This delays the setting and hardening of the concrete as no water is available for chemical reaction; ultimately resulting to large volume of pores, hence low strength is gained (Neville and Brooks, 2006; Usman, Adebitan, Kwari and Gyang, 2013). However, in maintaining standard, admixtures are used. Retarders are admixture that extend the hydration induction period, thereby lengthening the setting times (Lea, 1988). Sugar, carbohydrate derivatives, soluble zinc salts, soluble borates exhibits retarding action (Neville and Brooks, 2006). Lea (1988) asserts that sugar is a coating admixture which in the presence of water, cement particle sends out a swarm of calcium ions into the surrounding water and any substance capable of immobilizing or delaying this surge slows down the interchanges between the water and the particle, thus, retarding the hydration process.

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 aluminates but do not alter the composition of hydration products (Neville and Brooks, 2006; Lea, 1988). The delay in setting of the cement paste can be exploited to produce architectural finish of exposed coarse aggregate (Neville and Brooks, 2006). Sugar, carbohydrate derivatives and some salts exhibit retarding action (Neville and Brooks, 2006; Lea, 1988; Ramachandran, Lowery, Wise and Polomark, 1993). It is challenging that retarders modify crystal growth or morphology, becoming absorbed on rapidly formed membrane of hydrated cement and slowing down the growth of calcium hydroxide nuclei, thus, forming a more efficient barrier to further hydration than is the case without a retarder (Neville and Brooks, 2006). The retarder is believed to be finally removed from solution by being incorporated into the hydrated material without necessarily forming different complex hydrates (Usman *et al*, 2012). Retarders can be useful when concreting in hot weather, when the normal setting time of concrete is shortened by the higher ambient letter temperature (Neville and Brooks, 2006). Commercial lignosulfonates used in admixture formulations are predominantly calcium-sodium based with sugar content of 1-30% (Rixom and Mailvaganam, 2007).

In both Roman and Egyptian times, it was discovered that adding volcanic ash to a mix allowed it to set underwater. Similarly, the Romans knew that adding horse hair made concrete less liable to crack while it hardened, and adding blood made it more frost-resistant. Crystallization of strätlingite and the introduction of pyro-classic clays create further fracture resistance. Since then, admixtures are added to concrete. These ingredients may accelerate or slow down the rate at which the concrete hardens, and impart many other useful properties including increased tensile strength, entrainment of air, and / or water resistance. Nigeria is not exceptional, the high cost of moving plants from one site to the other, requires a catalyst such as concrete admixture. These retarders are used to take care of delays on a job site e.g. distance during transporting concrete or even extreme temperatures that cause concrete to set faster than normal.

Infrastructures are inadequate lacks space to accommodate construction plants and equipment especially when sites are located on / or along the roadways (Usman *et al*., 2013). For instance, mixing plants may not be available on construction sites, rather, and in some cases, mixed concrete has to be transported over a long distance. Therefore, the need for concrete retarders cannot be overemphasized as these retarders are helpful in delaying the setting time of concrete.

It is disheartening that contractors shun the use of set – retarders due to high cost than the conventional retarding agents. This practice has been responsible for low quality concrete production as well as defective concrete structures (Usman *et al.*, 2013). Even though, sugar is readily available and cheap, it may not affect the setting – time of cement as retarders and the relative compressive strength of concrete. Therefore, sugar may likely fill the gap of conventional retarding agents in Bauchi and the country at large. Hence, the study aims at determining the impact of sugar solution on setting – time of Ordinary Portland Cement (OPC) paste and the compressive strength of concrete through the following objectives: to ascertain the concentration percentage (%) of sugar by weight of cement on the setting – time of cement paste and to investigate any marginal compressive strength on concrete due to the concentrations of sugar percentage by weight of cement.

The concentration percentage (%) of sugar by weight of cement on ordinary Portland cement paste that impact on the setting-time

Set-retarding admixture generally delay the setting-time and reduce the subsequent rate of hydration of cement (BS5075). Several compounds have been found to exhibit retarding action in concrete in its performance (Part 1 of the British Standard, BS5075). Some of these compounds include soluble zinc salts, soluble borates and carbohydrate derivatives. Studies has shown that while investigating concrete admixtures, the concentration (dosage) of the admixture that will have impact on the concrete is usually difficult (Usman *et al*., 2013, Dupke, 2010, Okafor, 2008).Usually, admixture dosage are less than 5% by mass of cement and are added to the concrete at the time of batching/mixing (Dupke, 2010).

Okafor (2008) studied the Potentials of Cassava Flour as a Set-Retarding Admixture in Concrete and found there was delay in both the initial and final setting time of cement by adding cassava flour up to 3% of the weight of cement. As the delay in the initial and final setting time increases, the dosage increase in the level of admixture. Within the range of 3% dosage level, the delay in the initial and final setting time ranges between 5 hours and 6 hours respectively. However, when 3% level of cassava flour was added, there was a decrease in the initial setting time of cement. As the initial setting time increases so also the dosage level of cassava flour increases and the trend of the final setting time remains unaffected. The observed acceleration of the initial setting time could have been attributed to the increased cyanide content of the cement due to the increased quantity of cassava flour. The cyanide probably altering appreciably the alkalinity of the cement environment with consequent acceleration of the initial setting time. However, this condition appears to cease as cyanide becomes exhausted and the retarding action of the carbohydrate restored, hence, the final setting time remains unaffected.

There appears to be an optimum dosage level of cassava flour as a set-retarding admixture. The observed delay in the setting time of cement achieved by the addition of up to 3% cassava flour was based on the requirements by the relevant British Standard [1, 22]. Furthermore, acceleration of the initial setting time occurs when the dosage level of cassava flour exceeds 3%, hence, 3% cassava flour by weight of cement appears to be the optimum dosage level of the admixture; so also applicable with sugar.

Marginal Compressive Strength on Concrete due to the concentration percentage of Sugar by weight of Cement

Concrete has relatively high compressive strength, but much lower tensile strength (Neville and Brooks, 2006, Usman *et al*., 2012). So concrete is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops. Concrete has a very low coefficient of thermal expansion and shrinks as it matures. All concrete structures crack to some extent, due to shrinkage and tension. Concrete that is subjected to long-duration forces was prone to creep.

Different mixes of concrete ingredients produce different strengths. Concrete strength values are usually specified as the compressive strength of either a cylindrical or cubical specimen, where these values usually differ by 20% for the same concrete mix (Neville and Brooks, 2006, Usman *et al*., 2012).The main property of concrete is the compressive strength; therefore, when adding any admixture to concrete, the investigation of any (positive/ negative) marginal (difference) in compressive strength of the concrete must be noted (Dupke, 2010; Neville and Brooks, 2006; Usman *et al*., 2012).

Similarly, Okafor (2008) observed from his results that the trend of compressive strength development with age for concrete containing cassava flour admixture was similar to that obtained for the control concrete in the case of sugar admixture. In all cases, the compressive strength continues to increase with age and that, for concretes containing cassava flour in excess of 3% dosage level, however, the strength remain much lower than the control concrete at all ages. Lower strength could have been attributed to the prolonged retarding action of cassava flour due to the high dosage level of the admixture. These high dosage levels of cassava flour admixture are detrimental to the strength of concrete as no recordable strength is developed after 3 days and 7 days of age by concretes containing 7% and 10% dosage level of the admixture respectively. Therefore, the compressive strength of concretes with admixture dosage level of 1% to 3% were observed to be much closer to the control concrete thereby reducing the strength of the concretes at early ages.

A closer examination shows that concretes with admixture dosage of 1% to 3% developed higher strengths than the control concrete after 14 days. The higher the strength exhibited by the concretes at these ages suggests that the residual retarding effect of cassava flour is less significant after about 14 days, and strength development at this age is governed by other factors. The major factor contributing to the higher strength development enhanced workability and improved the degree of compaction achieved by the addition of cassava flour in concrete.

MATERIALS AND METHOD

Material

Sugar

Sugar used for the experiment was sucrose crystals ($C_{12}H_{22}O_{11}$). It was obtained from Bauchi metropolis market. The sugar was used at concentrations of 0, 0.05, 0.06, 0.08, 0.10, 0.20, 0.40, 0.60, 0.80, and 1% by weight of cement. In addition, the compressive strength of the concrete was investigated at 3, 7 and 21 days cured.

Cement

The cement used was ordinary Portland cement marketed by Dangote (Nig.) Ltd also obtained from the Bauchi Metropolis market.

Aggregates

The coarse aggregate used were graded crushed granite with specific gravity 2.65 and maximum nominal size with percentage by weight passing different sieve sizes in accordance with BS 8812-101:84 (BSI 2002) and BS 8812:103.1 (BSI 2002b). The sand used was natural river bed quartzite zone 2 type in accordance with BS 882 (BSI 2002c). The specific gravity of the sand was 2.65 and percentage by weight passing different sieve sizes in accordance with BS 8812-103.1 (BSI 2002b)

Water

Water was obtained from the tap.

Curing and Sugar % content by weight of Cement

The samples were cured for 3, 7 and 21days respectively. The percentage of sugar content used by weight of cement were 0, 0.05, 0.06, 0.08, 0.10, 0.20, 0.40, 0.60, 0.80 and 1%.

Procedure

Sugar crystals ($C_{12}H_{22}O_{11}$) were weighed and dissolved in the required 0.6 weight of water before mixing. The materials were batched by weight and mixed manually.

Each mould was filled in three layers, each layer of concrete was properly compacted by not less than 35 strokes of 25mm square steel punner to obtain sufficient compaction and the mould top finished by trowel in accordance with BS 1881: Part108 (BSI 1996) and BS1881: Part111 (BSI 1997). Three cubes were cast for each mix parameter (concentration of sugar %) and was crushed at maturity of 3, 7 and 21 days. Curing of cubes was done in compliance with British Standards Institution BS EN 12390-2 (BSI 2003) requirements. The maximum aggregate size used complied with single sized aggregates classification in accordance with BS 882 (BSI 2002c).

For the setting time, the cement was thoroughly mixed with the sugar solution of the different concentration (0-1% by weight of cement). The measurement of setting times and cement paste were done using Vicat apparatus in conformity with EN 196-3 (1987) standard.

RESULTS AND DISCUSSION

Impact of Sugar on Setting Time of Ordinary Portland Cement (OPC)

Results indicate a markedly delay in both the initial and final setting time of cement (Table 3 and Fig. 1). The increase in initial and final setting times were obvious to sugar content of 0.06%. Reduction in setting time begins from 0.08% sugar content and flash setting occurs from 0.2% to 1%.

Table 3: Impact of Sugar on Setting Time of Cement Paste

Sugar content by % weight of cement	Initial setting time: hr (min)	Final setting time: hr (min)
0.00	1.92 (115)	5.12 (310)
0.05	2.62 (157)	6.48 (389)
0.06	3.25 (195)	7.10 (426)
0.08	2.67 (160)	6.62 (397)
0.10	2.25 (135)	5.22 (313)
0.20	1.73 (104)	3.13 (188)
0.40	1.33 (68)	1.63 (98)
0.600.90 (54)	1.32 (79)	
0.80	0.18 (11)	0.33 (20)
1.00	0.13 (8)	0.18 (11)

Source: *(Field Survey, 2016)*

The Impact of Sugar on Compressive Strength of Concrete

Properties of fresh concrete as well as compressive strength values of concrete cubes at varying levels of sugar content are shown in Table 4 and Fig. 1. Strength gain peaks at 0.05% sugar content at 3 days and at 0.06% sugar content at 7, and 28 days respectively. Complete early strength loss was observed at 3 and 7 days on sugar content of 0.4-1%. Strength loss at 28 days was significant from sugar content of 0.08 - 1%. There was no significant effect of sugar on slump and compaction factor values of fresh concrete.

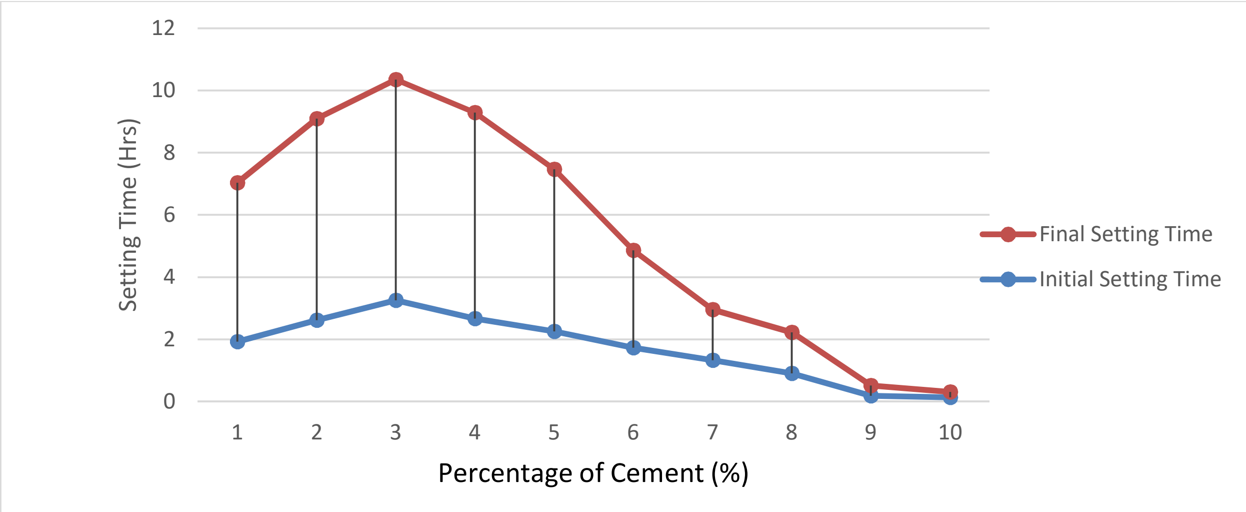

Figure 1: Impact of Sugar on Setting Time of Cement Paste

Table 4: Impact of Sugar on Physical Properties of Concrete

Sugar content by % weight of cement	Average Compressive Strength (N/mm^2)			Compaction Factor	Slump (mm)
	3 days	7 days	28 days		
0.00	12.67	17.58	34.10		
0.05	12.69	17.47	35.00	0.89	54
0.06	12.06	17.61	35.20	0.90	53
0.08	12.35	17.59	30.00	0.91	51
0.10	11.77	17.46	29.00	0.91	57
0.20	5.65	11.25	27.93	0.91	55
0.40	0.00	1.17	27.30	0.86	59
0.60	0.00	0.00	25.18	0.86	54
0.80	0.00	0.00	23.64	0.92	52
1.00	0.00	0.00	11.35	0.90	56

Source: *(Field Survey, 2016)*

Results obtained indicate that sugar has impact on setting time of cement. Sugar content of 0.06% by weight of cement can delay initial and final setting time by 1.33 hours (80 minutes) and 1.93 hours (116 minutes) respectively. No adverse effect on cement paste has been observed at this level of sugar concentration. The delay in setting time on concrete at this level of sugar content could be useful in preventing cold joints and in reducing early setting of cement in hot weather concreting. However, Sugar above 0.10% by weight of cement accelerated the setting time of cement and was characterized by cracks at the surface and color was black from earlier grayish sample.

In addition, for the impact of sugar on compressive strength of concrete, results shows that Strength gain peaks at 0.05% sugar content at 3 days and at 0.06% sugar content at 7, and 28 days respectively. The strength gain at 28 days amounts to 3.23%. Complete early strength loss was observed at 3 and 7 days at sugar content of 0.4-1%. Strength loss at 28 days was significant from sugar content of 0.08 – 1%. There is no significant effect of sugar on slump and compaction factor values of fresh concrete. The compressive strength results in Table 3 show that the speed of setting time of cement paste has adverse effect on the strength of the concrete (Neville and Brooks, 2006; Usman *et al*, 2013).

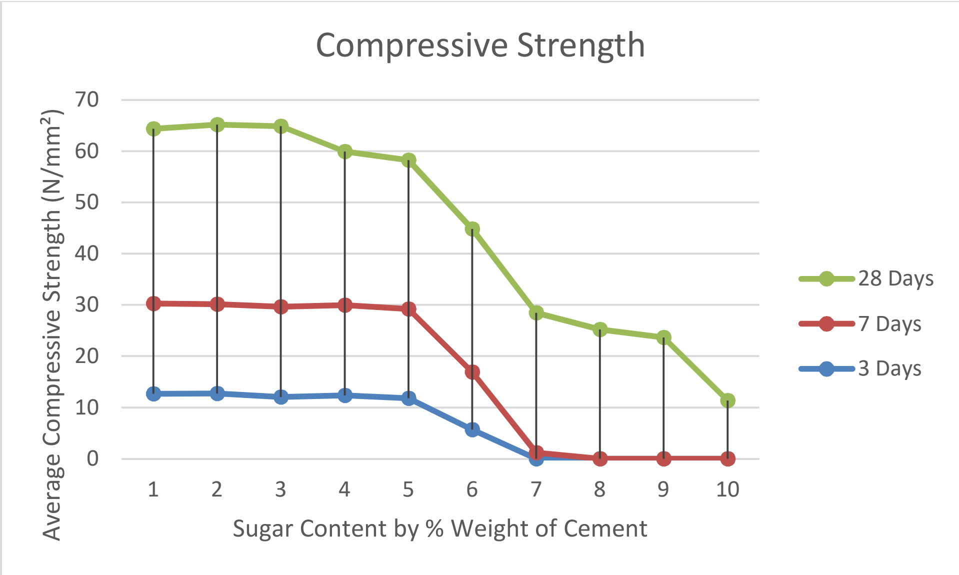

Figure 2: Impact of sugar on compressive strength of concrete.

CONCLUSION

Based on the findings, the study concludes that:
1. Sugar delays the setting time of cement by up to 1.33 hours at dosage level of 0.06% by weight of cement.
2. There was no effect on the workability and compaction using sugar as admixture in concrete.
3. Higher compressive strength can be achieved in concrete by the use of sugar as admixture.
4. The optimum dosage level of sugar as a set-retarding admixture is 0.06% by weight of cement.
5. Consequently, sugar perform satisfactorily as a set-retarding admixture in concrete.

Recommendations

1. Sugar should be used as a retarder but when it is used in excessive amount, reverse its properties.
2. The quantity of the sugar and other related quantities must be adequately measured in the production process. Sugar content of 0.06% by weight of cement can improve compressive strength of concrete by 3.23% at 28 days and delay initial setting time by 1.33 hours (80 minutes).
3. Sugar has no adverse effect on concrete and cement paste.
4. The delay in setting of concrete at 3 and 7 days for sugar content could be useful in preventing cold joints and in reducing early setting of cement in hot weather concreting.

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