AU J.T. 14(3): 225-228 (Jan. 2011)

Effects of Sugar on Physical Properties of Ordinary Portland Cement Paste and Concrete

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Abstract

Effects of sugar 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 on cement paste and grade C35 concrete cured at 3,7,14 and 28 days was investigated using ordinary Portland cement in the laboratory. The initial setting time of cement paste was longest at 0.06% sugar content with soundness value of 0.35 mm. Flash setting with no increase in strength was observed at sugar content of 0.2-1%. The compressive strength test results show some marginal strength gains at all ages but peaks at 11.84% at 3 days at 0.05% sugar content.

Keywords: *Cement paste, compressive strength, concrete, setting time, soundness.*

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 (Neville 2006; Lea 1988). 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 (Neville 2006; Lea 1988; Ramachandran *et al*. 1993). Sugar belongs to the type of retarders that can hold up setting and hardening indefinitely and Forsén called them 'cement destroyers' (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 nuclei thus forming a more efficient barrier to further hydration than is the case without a retarder (Neville 2004). 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 (Neville 2004). 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 and 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 no possible (Neville 2006). However, Portland cement concrete without special treatment has been known to be attached by sugar solutions. Light refined molasses are stated to have a more aggressive action than dark molasses on concrete (Lea 1988).

The sugar used in this work is laboratory sucrose crystals ($C_{12}H_{22}O_{11}$) with the following specifications; water insoluble matter 0.003%, Loss on drying 0.5%, Sulphate ash 0.005%, Nitrogen compound 0.002%, Cadium(Cd) 0.000005%, Iron(Fe) 0.00001%, Nitrate (N) 0.00005%, Chlorine(Cl) 0.0005%, Sulphate(SO_4) 0.002%, Copper (Cu) 0.001%, Lead (Pb) 0.00%, Zinc(Zn) 0.00001%.

Methodology

The concrete mix was designed to attain 35 N/mm^2 at 28 days with the following composition of materials; cement 404.94 kg/m^3;

sand 645.93 kg/m^3; coarse aggregate 1,340.99 kg/m^3; water 169.88 kg/m^3. The aggregate used is graded crushed granite with a specific gravity of 2.68 and 20 mm maximum nominal size with the following percentage by weight passing sieve sizes: 20 mm (100); 14 mm (95.53); 10 mm (60); 5mm (8); 3.35 mm (0.22) in accordance with BS 8812-101:84 (BSI 2002) and BS 8812-103.1 (BSI 2002b). The sand used is natural river bed quartzite zone 2 type in accordance with BS 882 (BSI 2002c). The specific gravity of the sand is 2.51. Sieve analysis of the sand gives the following percentage weights passing sieve sizes: 5 mm (95.8); 2.36 mm (88.3); 1.18 mm (72.1); 600µm (48.5); 300 µm (19.2); 150 µm (3.9) in accordance with BS 8812-103.1 (BSI 2002b). Sugar crystals were weighed and dissolved in the required 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 compacted by not less than 35 strokes of 25 mm square steel punner to obtain sufficient compaction and the mould top finished by trowel in accordance with BS 1881: Part 108 (BSI 1996) and BS 1881: Part 111 (BSI 1997). Three cubes were cast for each mix parameter and crushed at maturity in accordance with BS EN 12390-2 (BSI 2003). Curing of the cubes was done in compliance with British Standards Institution BS EN 12390-2 (BSI 2003) requirements. The maximum aggregate size used complies with single sized aggregates classification in accordance with BS 882 (BSI 2002c).

The measurement of setting times of standard cement paste and soundness was done using Vicat and Le Chatelier apparatus in conformity with EN 196-3 (1987) standard.

Data Presentation and Discussion

The results of effects of sugar on setting times and soundness of cement paste are presented in Table 1. The increases in initial and final setting times are apparent up 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%. Cement paste samples at increased curing temperature containing 1% sugar has been reported to have very quick hydration (Garci Juenger and Jennings 2002). Cement pastes with sugar content from 0.6% have values of initial setting time below minimum time of 60 minutes requirement prescribed by ENV 197-1 (1992) for cements with strength up to 42.5 MPa.

Table 1. Effect of sugar on physical properties of cement paste.

Sugar content as % of weight of cement	Initial setting time: hours (min)	Final setting time: hours (min)	Sound-ness (mm)
0	3.667(220)	4.250(255)	0.50
0.05	4.583(275)	5.900(354)	0.40
0.06	5.233(314)	7.100(426)	0.35
0.08	3.983(239)	5.483(329)	0.75
0.10	3.500(210)	5.167(310)	0.28
0.20	2.533(152)	3.167(190)	0.01
0.40	1.333(68)	1.633(98)	0.06
0.60	0.900(54)	1.317(79)	0.05
0.80	0.183(11)	0.333(20)	0.04
1.00	0.133(8)	0.183(11)	0.03

There is apparently no correlation between the speed of setting of cement paste and strength gain from sugar level of 0.08 to 1%. The soundness of cement paste is a measure of expansion of set cement paste. It is important that cement should not undergo large volume change, since this could inevitably lead to a disruption of the hardened cement paste (Neville 2006). Because unsoundness of cement may not be apparent until after a period of months or years, the Le Chatelier apparatus is for testing the soundness of cement in an accelerated manner (Neville 2006). The maximum value allowed by ENV 197-1 (1992) standard is 10 mm. The use of sugar up to a value of 0.06% actually lowers the value of cement paste expansion. The graphical effects of sugar content on setting times and soundness of cement paste are shown in Figs. 1 and 2.

Properties of fresh concrete and compressive strength values of concrete cubes at varying levels of sugar content are shown in Table 2. Strength gain peaks at 0.05% sugar content at 3 days and at 0.06% sugar content at 7, 14 and 28 days respectively. The strength gain at 28 days amounts to 3.62%. Complete early strength loss is observed at 3 and 7 days at sugar content of 0.4-1%. Strength loss at 28

days is 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 2 show that the speed of setting of cement paste as shown in Table 1 and the rapidity of hardening i.e. of gain of strength are independent of one another (Neville 2006). Graphically Figures 3 and 4 show the effects of sugar content on the compressive strength of concrete and corresponding strength gain/loss. Thou Shetty (2004) suggest an upper limit of 0.1% of sugar in concrete with little effect on hydration, that limit is apparently not safe for concrete from this study.

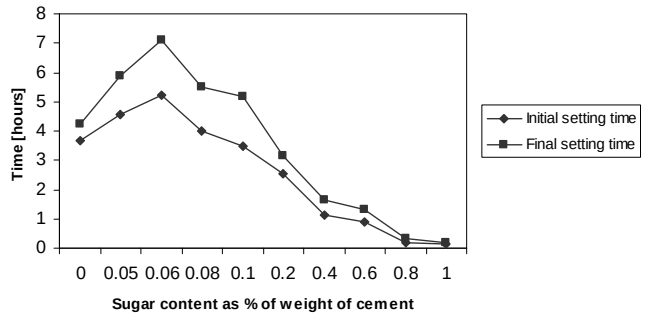

Fig. 1. Effect of sugar on setting times of cement paste.

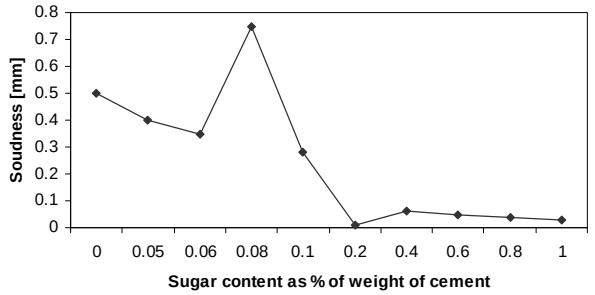

Fig. 2. Effect of sugar on soundness of cement paste.

As observed by Neville (2006), when sugar is used as a set retarder, it can severely reduce early strength of concrete, but that beyond about seven days there is an increase in strength of several percent compared with non-retarded mix (Neville 2006). Work on molasses in concrete at concentrations of 0.2, 0.4, and 0.7% at 1, 3, and 7 days shows slight increase in concrete strength at all ages with no adverse effect over long time long time periods of up to 900 days (Jumadurdiyev *et al*. 2004).

Table 2. Effect of sugar on physical properties of concrete cubes at w/c = 0.42.

Sugar content as % of weight of cement	Average compressive strength (N/mm^2)					
	3 days	7 days	14 days	28 days	Compaction factor	Slump, mm
0	16.05	26.62	36.44	40.88		
0.05	17.95	26.07	36.60	41.99	0.889	54
0.06	14.62	26.94	37.12	42.36	0.895	53
0.08	16.57	27.03	34.51	38.88	0.906	51
0.10	16.39	26.21	31.32	35.43	0.909	57
0.20	12.82	20.05	25.03	32.64	0.907	55
0.40	0	0	20.17	32.08	0.86	59
0.60	0	0	3.00	31.47	0.858	54
0.80	0	0	2.20	30.66	0.918	52
1.00	0	0	1.07	17.4	0.895	56

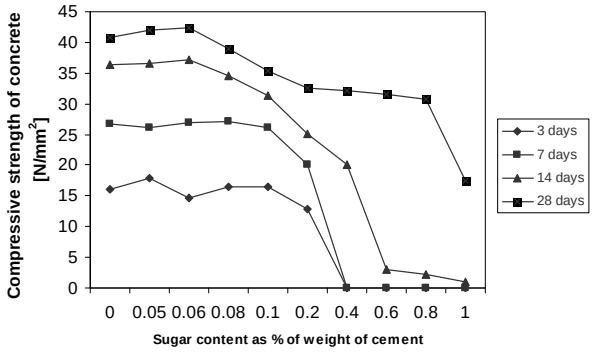

Fig. 3. Effect of sugar on compressive strength of concrete at w/c = 0.42.

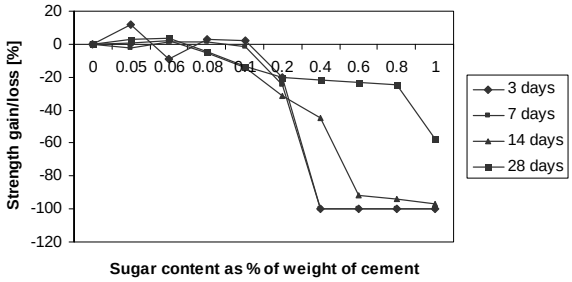

Fig. 4. Effect of sugar content on strength gain/loss.

Conclusion

Retarders should only be used for concreting where competent personnel and adequate quality control of the production processes are available. The quantity of the retarder and other related quantities must be adequately metered in the production process. Sugar content of 0.06% by weight of cement

can improve compressive strength of concrete by 3.62% at 28 days and delay initial setting time by 1.556 hours (94 minutes). No adverse effect on concrete and cement paste have been observed at this level of sugar concentration for the ages of concrete cubes studied. The delay in setting of 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.

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