THE EFFECT OF SUGAR ON SETTING-TIME OF VARIOUS TYPES OF CEMENTS

Bazid Khan and*
*Bulent Baradan***

ABSTRACT

The objective of this research is to investigate the influence of sugar s of different origins (Beet & Cane) on the setting times of cement pastes. Sugar is incorporated with three different types of cements under three different curing conditions (Temp. & R.Humidity).

The test results revealed that, under normal curing conditions (Temp.=22^{0}C & R.H.≅60%), the efficiency of sugar in retarding cement setting becomes higher with increasing sugar-content upto a certain limit. However, with further increase in sugar content, its retarding efficiency started to decrease, until at certain higher content it showed reverse effects (i.e, it accelerated the cement setting). Furthermore, sugar causes higher retardation when added a few minutes after the mixing of water and cement.

INTRODUCTION

When water is added to cement, it sets and hardens gradually under normal climatic conditions. But in some countries, including Pakistan, higher summer temperatures, low relative humidity and hot wind blowing cause rapid evaporation of water from the fresh concrete surface. Consequently concrete sets earlier and no proper time is left available for concreting operations. For example, it has been reported that, when the temperature of cement mortar wit a water/ cement (w/c) ratio of 0.6 is increased from 27.8^{0}C to 45.5^{0}C both the initial and final setting times are nearly halved[1]. Further problems also arise such as rapid decrease of slump[2], formation of cold joints and plastic shrinkage cracking[3], increased difficulty in air entrainment[2], enhanced permeability and reduced durability[4], corrosion of steel[5], and reduction in ultimate strength of concrete[6].

Inorder to provide proper time for concreting operation, especially when unavoidable delays between mixing and placing occur, and to save concrete from other detrimental effects of adverse climatic conditions, cement set retardation/or use of retarding admixtures is necessary. " An admixture is a material other than water, aggregates, hydraulic cement and fiber reinforcement, used as an ingredient of concrete or mortar and added to a batch before or during mixing. A retarding admixture/retarder is an admixture that retards the setting of cement concrete, mortar or grout[7]".

A retarding admixture causes cement set retardation by the following mechanisms:

1) Adsorption of the retarding compound on the surface of cement particles, forming a protective skin, which slows down hydrolysis;
2) Adsorption of the retarding compound onto nuclei of calcium hydroxide, poisoning their growth, which is essential for continued hydration of cement after the end of induction period;
3) Formation of complexes with calcium ions in solution, increasing their solubility and discouraging the formation of the nuclei of calcium hydroxide, refereed to in (2);
4) Precipitation around cement particles of insoluble derivatives of the retarding compounds formed by reaction with the highly alkaline aqueous solution, forming a protective skin[8].

Retarding admixtures are mainly based on materials having lignosulfonic acids and their salts, hydroxy-carboxylic acids and their salts, sugar and their derivatives and inorganic salts, such as borates; phosphates, zinc and lead salts[9].

Sugar is a carbohydrate, a substance composed of only carbon, oxygen and hydrogen. Sucros, fructose, dextrose, lactose and other 'Oses' are members of this chemical class. It occurs in sugar cane and sugar beet. The basic unit of carbohydrate is a linear chain of four to seven carbon atoms with a hydoxyl group on each one, the terminal carbon being an aldehyde.

Owing to the retardation of ordinary Portland cement, sugar falls into three categories: non-retarding, good retarders and most effective retarders. The non-reducing sugars, α-methyl glucoside and α-α trehalose, are effectively non-retarding; the reducing

* Assistant Professor B-Tech, Civil, Govt. College of Technology, Peshawar. ** Faculty of Civil Engieering, Dokuz Eulul University, Izmir, Turkey.

sugars, glucose; maltose, lactose and celloboise, are grouped together as good retarders, while the non-rdeucing sugars (which have a five-member ring) sucrose and raffinose are far the most effective retarders. Sugars have been categorized as 'cement destroyer' and when small amounts of sugar (1% by weight of cement) are added to Portland cement paste at the onset of mixing, hardening may be delayed indefinetly[10].

The retarding action of sugar is probably by the prevention of the formation of calcium silicate hydrate (CSH)[2].

EXPERIMENTAL PROGRAM

Materials: Two types of sugars of different origins (sugar beet & sugar cane) and three different types of cements, designated as PKC/A42.5, PKC/B32.5 and PC42.5 (According to Turkish Standard No.20), were used. Their oxide and compound compositions are shown in Table 1.0.

Table - 1.0: Oxide and Compound composition of cements

Name	Abbreviation	PKC/A 42.5	PKC/B 42.5	PC 42.5
Silica	Sio_2	23.79	33.06	19.30
Alumina	Al_2O_3	6.33	7.43	5.38
Ferric oxide	Fe_2O_3	3.52	3.33	2.89
Lime	CaO	57.20	45.03	62.78
Magnesia	MgO	0.69	0.90	1.66
Sodium	Na_2O	-	0.10	0.55
Potassium	K_2O	1.03	1.46	0.75
Sulfuric Anhydride	SO_3	2.00	2.07	3.17
Chlorine	CL^-	0.019	0.0266	0.0089
Loss on ignition	L.O.I	2.14	4.21	3.29
Undetermined	-	3.28	-	-
% Free lime	% F.CaO	1.37	0.39	0.77
Insoluble residue	I.R	-	29.06	0.42
Soundness (mm)	-	2.00	3	1.00
Specific gravity	-	3.03	-	3.08
Weight per liter (g/lt)	-	984	910	1050
Fineness-specific surface (cm^2/g)	-	3661	4963	3759
Lime saturation factor	L.S.F.	-	196.35	99.15
Hydraulic modulus	H.M.	-	3.05	2.31
Silica modulus	S.M.	-	0.37	2.29
Alumina modulus	A.M.	-	2.23	1.86
Tricalcium silicate	C_3S	-	-	59.51
Dicalcium silicate	C_2S	-	-	10.76
Tricalcium aluminate	C_3A	-	-	9.37
Tetracalcium aluminoferrite	C_4AF	-	-	8.79

Procedure

The setting time tests were performed on cement paste of standard consistency. The quantity of cement and water used per test for each type of cement are:

Type of cement	Amount of cement9g)	Water (ml)	w/c ratio
PKC/A42.5	400	130	32.50
PKC/B32.5	385	130	33.75
PC42.5	400	110	27.50

For one type of tests, the sugar was dissolved in the mixing water before adding it to cement. Vicat apparatus was used and Turkish Standard(TS) No.19 was followed for taking initial and final setting-times readings. According to TS-19, initial set is said to have taken place when the needle(1.13mm dia.) of Vicat apparatus ceases to pass 3-5 mm above the bottom of cement paste taken in a Vicat mould (top internal dia.= 80mm, bottom int. dia.= 90mm, height = 40mm). Final setting is said to have occurred when the needle penetrates the cement paste to a maximum depth of 1mm. In both the cases, the setting-time is reckoned from the moment when the mixing-water is added to the cement.

For other type of tests, half of the mixing-water containing no sugar was added to the cement and in the remaining half of the mixing-water, sugar was dissolved and added, 10 minutes later on, to the cement.

Curing Conditions

Inorder to simulate the approximate outdoors climatic conditions, the following three categories of curing conditions were provided, to the test specimens:

1) Curing condition first (CC-I): Temperature = 22^{0}C, Relative Humidity = 55-65%
2) Curing condition second (CC-II): Temperature = 35^{0}C, Relative Humidity = 35-45%
3) Curing condition third (CC-I): Temperature = 50^{0}C, Relative Humidity = 25-35%

Test Data And Presentation Of Results

Setting-time tests with varying sugar-contents (expressed as a percentage by weight of cement) were performed, under the specified curing conditions. The average of three test readings was taken as the final reading. These are shown in the following Tables 1.1 to 1.9 and Figures 2.1 to 2.6 together with Tables 1.10, 1.11 and Figs. 1.7 and 1.8 for effect of stage of sugar incorporation and of cane sugar and beet-sugar.

A) RESULTS FOR CEMENT PKC/A42.5

Table - 1.1: Setting time and relative retarding effects of sugar on cement setting under CC-I

Sugar (%)	000	0.04	0.05	0.06	0.70	0.10	0.20	0.25	0.30	0.4/0.5
Initial setting time(mins)	143	292	325	512	660	840	590	260	42	20
Final setting time(mints)	204	364	402	569	720	960	790	649	72	40
Initial set retardation	1	2.04	2.27	3.58	4.62	5.87	4.13	1.82	0.29	0.14
Final set retardation	1	1.78	1.97	2.79	3.53	4.71	3.87	3.18	0.35	0.20

The results of Table 1.1 are graphically shown in Figures 1.1 and 1.2.

Table 1.2 Setting time and relative retarding effects of sugar on cement setting under CC-II

Sugar (%)	000	0.04	0.05	0.06	0.70	0.80
Initial setting time(mins)	96.5	172	256	309	331	417
Final setting time(mints)	131.5	214	306	354	383	481
Initial set retardation	1	1.80	2.68	3.24	3.47	4.37
Final set retardation	1	1.63	2.33	2.69	2.91	3.66

Table 1.3 Setting time and relative retarding effects of sugar on cement setting under CC-III

Sugar (%)	000	0.04	0.05	0.06	0.70	0.80
Initial setting time(mins)	78	156	184	238	278	323
Final setting time(mints)	102	187	216	280	319	392
Initial set retardation	1	2.00	2.36	3.05	3.56	4.14
Final set retardation	1	1.83	21.2	2.75	3.13	3.84

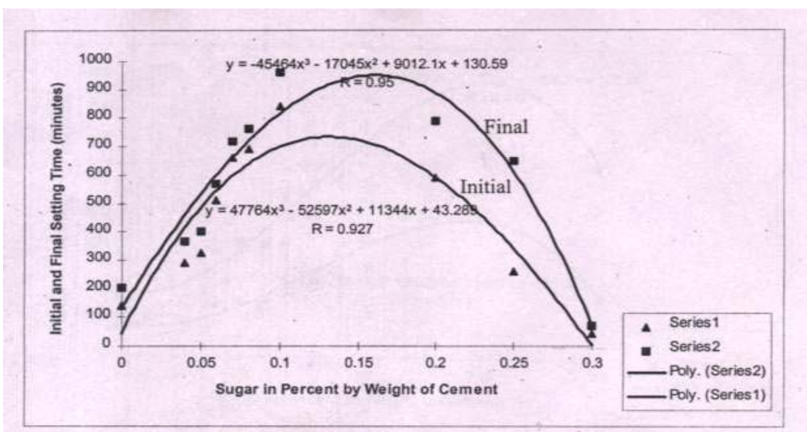


Figure - 1.1: Effect of Sugar on Setting Time of Cement (PKC/A 42.5) Under CC-I

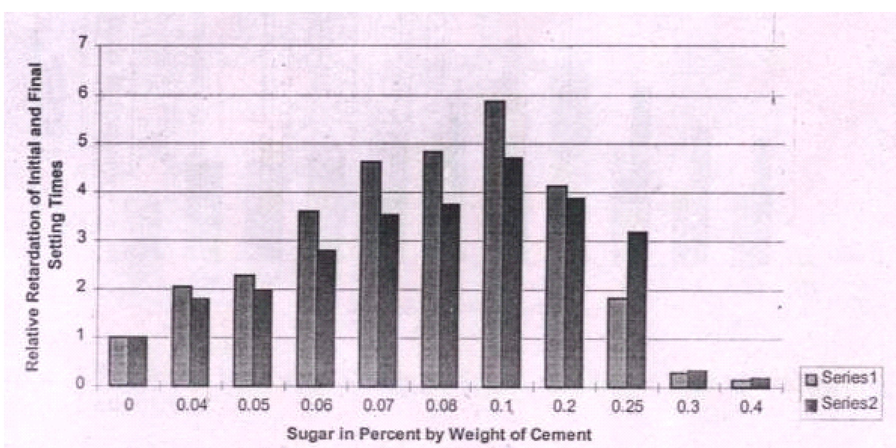


Figure - 1.2: Relative REtarding Effect of Sugar on Setting of Cement (PKC/A 42.5) Under CC-1

B) RESULTS FOR CEMENT PKC/B32.5

Table 1.4 Setting time and relative retarding effects of sugar on cement setting under CC-I

Sugar (%)	000	0.04	0.05	0.06	0.70	0.80	0.09	0.10	0.20	0.40	0.50
Initial setting time(mins)	88	148	157	164	189	204	293	342	178	125	113
Final setting time(mints)	172	300	333	322	402	494	517	660	550	430	395
Initial set retardation	1	1.68	1.78	1.87	2.15	2.32	3.33	3.90	2.02	1.42	1.28
Final set retardation	1	1.74	1.94	1.86	2.34	2.87	3.00	3.84	3.20	2.50	2.30

The results of Table 1.4 are graphically shown in Figures 1.3 and 1.4

Table 1.5 Setting time and relative retarding effects of sugar on cement setting under CC-II

Sugar (%)	000	0.04	0.05	0.06	0.70	0.80
Initial setting time(mins)	70	111	131	129	144	157
Final setting time(mints)	132	191	210	215	227	250
Initial set retardation	1	1.59	1.87	1.84	2.06	2.24
Final set retardation	1	1.45	1.59	1.63	1.72	1.89

Table 1.6 S[illegible] ent setting under CC-III

S	.80	0.09
I	3	82
F	51	133
I	.45	1.28
F	.47	1.29

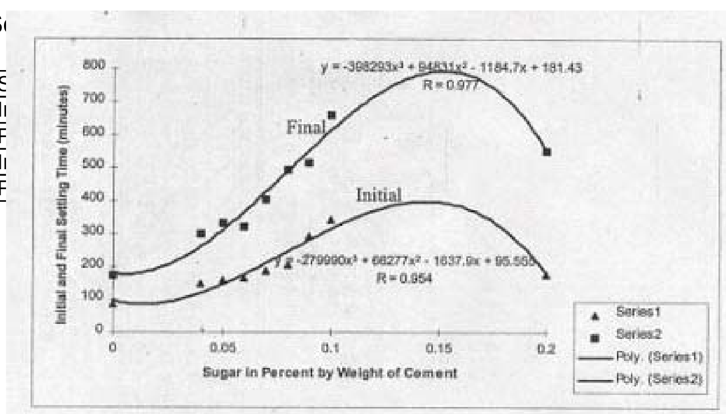


Figure - 1.3: Effect of Sugar on Setting Time of Cement (PKC/B 32.5) Under CC-I

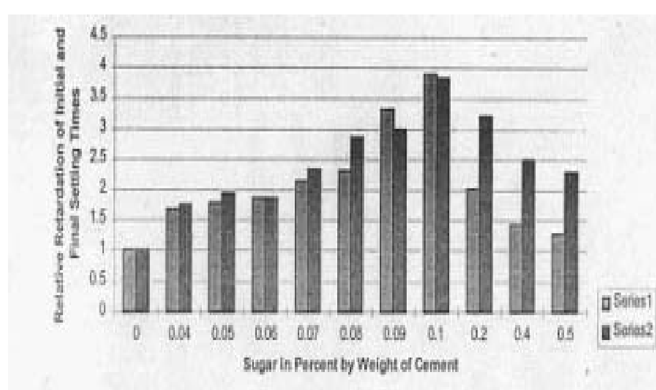


Figure - 1.4: Relative Retarding Effects of Sugar on Cement (PKC/B 32.5) Setting Under CC-I

C) RESULTS FOR CEMENT PC 42.5

Table 1.7 Setting time and relative retarding effects of sugar on cement setting under CC-I

Sugar (%)	000	0.04	0.05	0.06	0.70	0.10	0.20	0.30	0.40	0.50-2.0
Initial setting time(mins)	126	263	295	486	528	507	512	198	41	12
Final setting time(mints)	179	331	386	554	618	692	780	527	63	15
Initial set retardation	1	2.09	2.34	3.86	4.19	4.02	4.06	1.57	0.33	0.095
Final set retardation	1	1.85	2.06	3.09	3.45	3.87	4.36	2.94	0.35	0.08

The results of Table 1.7 are graphically shown in Figures 1.5 and 1.6

Table 1.8 Setting time and relative retarding effects of sugar on cement setting under CC-II

Sugar (%)	000	0.04	0.05	0.06
Initial setting time(mins)	122	238	273	327
Final setting time(mints)	148	268	305	365
Initial set retardation	1	1.95	2.24	2.68
Final set retardation	1	1.81	2.06	2.47

Table 1.9 Setting time and relative retarding effects of sugar on cement setting under CC-III

Sugar (%)	000	0.04	0.05	0.06
Initial setting time(mins)	91	154	201	222
Final setting time(mints)	108	182	238	255
Initial set retardation	1	1.69	2.21	2.44
Final set retardation	1	1.69	2.20	2.36

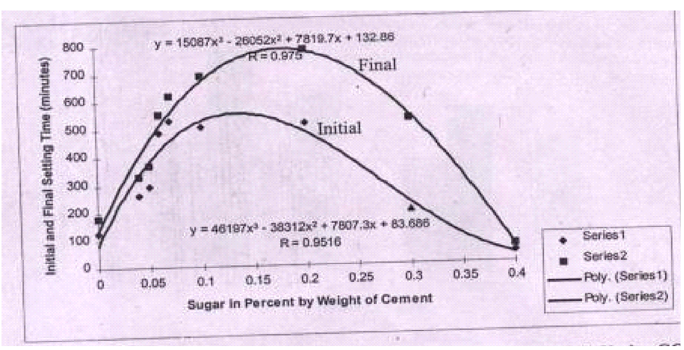


Figure - 1.5: Effect of Sugar on Setting Time fo Cement (PC 42.5) Under CC-I

Figure - 1.6: Relative Retarding Effect of Sugar on Setting of Cement (PC 42.5) Under CC-I

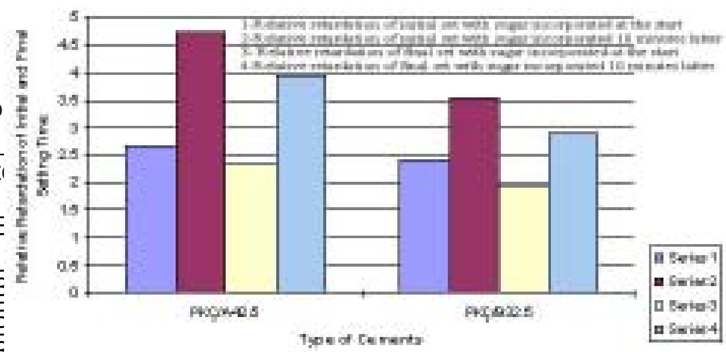
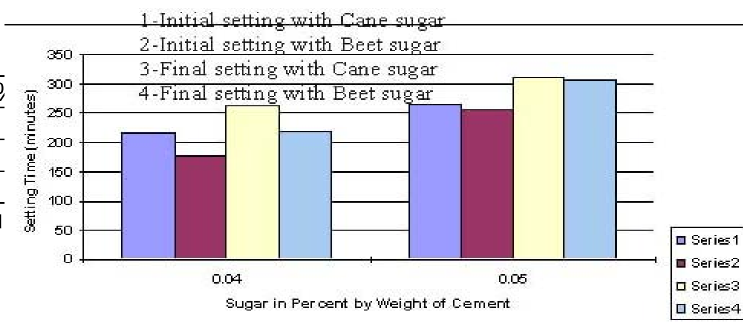


Figure - 1.7: Effect of the Stage of Incorporation of Sugar (0.05%) on Cement Setting Under CC-II

Table 1.10 Effect of the stage of sugar-incorpo

Cement type	Sugar(%)	Sugar added 10 minutes aft... water			
		Initial setting	F...		
PKC/A42.5	0.04	307	[illegible]	[illegible]	[illegible]
	0.05	448	[illegible]	[illegible]	[illegible]
PKC/B32.5	0.04	246	[illegible]	[illegible]	[illegible]
	0.05	319	442	215	297

The results of the Table1.10 are graphically shown in Figure 1.7



...ment-setting

Sugar (%...	[illegible]	[illegible]	Beet sugar	
	[illegible]	[illegible]	...al set	Final set
0.04	[illegible]	[illegible]	[illegible]	220
0.05	[illegible]	[illegible]	[illegible]	306

The resu...

Figure - 1.8: Effect of Cane and Beet Sugar on Cement Setting

CONCLUSIONS & FURTHER RESEARCH SUGGESTIONS

Conclusions:

1) Setting of cement was retarded by incorporation of sugar in cement under all conditions of curing. Consequently, setting-times were extended. The extension in setting-time was increasing with an increase in sugar content up to a certain limit ($\cong$0.15%) and then started to drop with further increase in sugar content. Sugar accelerated the cement-setting when a higher sugar content($\geq$0.3%) was used
2) Relatively low retarding tendency was shown by sugar under the second and third curing conditions.
3) 0.15% sugar-content acted as an Optimum Sugar Content for retarding the setting.

It was further noted that:

a) Practically same retarding tendency was shown by both Cane sugar and Beet sugar.
b) Increased retardation was caused by sugar when it was added to the cement a few minutes after mixing of cement and water.
c) The effect of sugar on cement setting is dependent upon the chemical composition of cement.

Following are some suggestions for further research:

There is need to examine other physical and chemical properties of sugar-incorporated cement pastes/ mortars, such as strength, shrinkage, permeability, etc.

REFERENCES

1. Fattuhi N.I. (1988). The setting of mortar mixes subjected to different temperatures. An International Journal of Cement and Concrete Research, Vol.15, No.1.
2. Neville A.M.(1995). Properties of concrete(2nd.ED) Longman Group Limited.
3. Portland Cement Association (1968). Design and Control of Concrete Mixes (11th.ED) 5420Old Orchard Road, Skokie, Illions 60076.
4. Kjellsen K.O., Det Wilter J.R. & GjΦrv E.O. (1990). Pore structure of plain cement pastes hydrated at different temperatures. An International Journal of Cement and Concrete Research, Vol.20, No.6.
5. Maslehuddin M., Page C.L. & Rasheeduzzfar (1997). Temperature effects on the pore solution chemistry in contaminated cements. Magazine of Concrete Research, Vol.49, No.178.
6. Al-Gahtani H.J.; Abbasi A-G.F. & Al-Moudi O.S.B. (1998). Concrete mixing design for hot weather: Experimental and statistical analysis. Magazine of Concrete Research, Vol.50, No.2.
7. ASTM Standards for cement and concrete, 1982
8. Banfil P.F.G. & Saunders D.C. (1986). The relationship between the sorption of organic compounds and cement and the retardation of hydration. An International Journal of Cement and Concrete Research, Vol.6, No.3.
9. Erdogan T.Y. (1997). Admixtures for Concrete, Middle East Technical University Ankara-Turkey.
10. Thomas N.L. & Birchall J.D. (1983) The retarding action of sugars on cement hydration. An International Journal of Cement and Concrete Research, Vol.13, No.6.