

Effect of Sugars on the Setting and Hardening of Cements

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This article describes the effect of increasing sugar concentrations on the compression strength of neat cement pastes. There exists an optimum sugar concentration at which the compression strength becomes maximum. Attempts have been made to correlate the compression strength data with differential thermal and thermogravimetric analysis of the set samples.

IT is well known that many organic admixtures containing a H-C-OH group markedly increase the setting time of cements, and sugars form an important class of such compounds. But the examination of the reported results on the effect of varying sugar concentrations on the setting and compression strength developed seem to be contradictory. It has been found that sugar is a retarder at all concentrations, the setting time increasing with increasing concentration¹. On the other hand in discussing "mixing water" for cements, it has been pointed out² that sugar at higher concentrations would act as an accelerator. Similarly, it is said that^{3,4} sugar at all concentrations is detrimental to cement strength. But calcium lignosulfonates, the well known commercial retarders containing reducing sugars are found⁴ to give a maximum strength at a particular concentration of sugar which depends on the type of cement used.

Considering the setting of individual cement components, recently Chatterjee⁵ reported the importance of reducing sugars in commercial lignosulfonates, on retarding the set of C₃S. Russian work⁶ on the hydration of C₄A in the presence of various sugars, also indicates the existence of optimum sugar concentrations at which the strength of hydrated samples is very much higher than the strength of the sample without additive.

An exact study of the effect of retarders is useful both from the point of view of special cements, like oil well cements, and the amount of impurities tolerated in mixing waters. We report here the effect of sucrose concentrations on the compressive strength of neat cement pastes. A partial correlation is established between thermo-analytical data of the hydrated cement samples and the compressive strength developed.

Experimental

A commercial sample of Portland cement was graded by passing through a 170 mesh (B.S.) sieve and analysed. The results of chemical analysis are indicated in Table 1. The sucrose sample used was

of analytical quality. Distilled water was used through all stages.

TABLE I

Compound	Symbol used in cement chemistry	% by weight	Present in cement as
CaO	C	60.0	3CaO SiO ₂ = C ₃ S
SiO ₂	S	22.1	2CaO SiO ₂ = C ₂ S
Al ₂ O ₃	A	6.6	4CaO Al ₂ O ₃ Fe ₂ O ₃ = C ₄ AF
Fe ₂ O ₃	F	5.0	3CaO Al ₂ O ₃ = C ₃ A
SO ₃	-	3.0	CaSO ₄
Insoluble residue	-	2.1	

Maintaining the water-cement ratio at a constant optimum value of 34.3%, 2×2" and 2.78×2.78" cement cubes were prepared from pastes with varying sugar (0.06%). To ensure that the concentration was the only factor affecting the compressive strength, the following precautions were taken: The same batch of graded cement was used throughout. The water-cement ratio was constant and the packing conditions were standardised using a vibrator. Cubes containing varying amounts of sugars were prepared as one lot and subjected to similar curing conditions i.e., first they were kept for 24 hr at 20°±3° and subsequently demoulded and placed in distilled water at 20°±3° for 7 or 28 days, after which their compressive strengths were tested on an Avery-Birmingham Machine. The values at a given concentration of sugar, repeated for at least 3-5 cubes, were reproducible to ±10 Kg/cm².

The anhydrous and hydrated cement samples were subjected to differential thermal and thermogravimetric analysis.

Results and Discussion

A summary of compression strength data of 7 days and 28 days cubes are shown in Table 2. The 7 days samples do not show much increase in strength at lower sugar concentrations and at higher concentrations, the strength falls. The behaviour of 28 days samples is interesting. There is a significant increase in strength at low sugar concentrations ($\sim 0.015\%$) and once again a slight increase around $\sim 0.125\%$. At higher concentrations ($> 0.6\%$), the cement paste did not set even after three days and hence the tests were not extended beyond this region.

TABLE 2

No.	Conc. of sugar, % by wt.	Strength in kg/cm ²	
		after 7 days curing	after 28 days curing
1.	0.000	353	394
2.	0.015	353	523
3.	0.030	343	503
4.	0.060	224	432
5.	0.125	—	774
6.	0.300	50	350

It has been established that one of the chief factors affecting the compression strength is the nature and habit of the hydrated products formed. For example fibrous crystals tend¹ to increase it. In C₃A and C₄AF sugars stabilise^{5,6} the hexagonal aluminate hydrate retarding their conversion into the cubic C₃A.6H₂O. Since the latter is known to decrease the compressive strength, the overall effect of the retarder will be to increase the same. Thermal analysis could be used to identify such different phases and establish a correlation between compressive strength and increase or decrease of one or more of the phases with varying concentrations in terms of water lost in the temperature regions characteristic of each of them.

DTA data indicated peaks corresponding to the well known cement hydration products, namely tobermorite, and possibly hillebrandite. TGA was performed up to 560°. On the basis of available literature data^{6,7} this region was divided into intervals where dehydration of one or other of the hydrated forms would be predominant. The weight losses in these regions on heating 28 days samples containing varying sugar concentrations are summarised in Table 3(a, b). The loss over the entire region may be identified with the total water content, i.e., water that exists as capillary, gel and combined water. We find that the total combined water has reached a maximum at 0.015% sugar where the compression strength also shows a maximum. But at 0.125% sugar where there is an auxiliary maximum in the compression strength, the total water loss is minimum. It is, interesting to note that if we break this up into loss over 0°-300° and 300°-560°, while the same picture is presented over the former region, in the latter it is the loss at

TABLE 3(A)

No.	Concn. of sugar, % by wt.	Wt. loss in % at °C		
		0-560	0-300	300-560
1.	0.000	14.4	8.9	5.5
2.	0.015	19.4	17.2	2.2
3.	0.030	13.4	10.4	3.0
4.	0.060	13.6	10.6	3.0
5.	0.125	11.2	7.0	4.2
6.	0.300	14.0	10.6	3.4

TABLE 3(B)

No.	Concn. of sugar, % by wt.	Wt. loss at °C					
		0-120	120-180	180-220	220-300	320-360	400-460
1.	0.000	3.5	2.8	1.3	1.3	0.7	1.0
2.	0.015	5.0	8.5	2.2	1.5	0.2	0.8
3.	0.030	0.8	7.2	1.6	0.8	0.4	0.8
4.	0.060	2.2	7.0	0.8	0.6	0.4	0.4
5.	0.125	2.4	3.2	0.4	1.0	0.4	0.4
6.	0.300	3.4	5.4	0.6	1.2	0.4	0.8

0.015% that is minimum and that at 0.125% that is maximum. The water lost between 0°-120° and 120°-180° is mainly due to dehydration of tobermorite crystals and tobermorite gel. Water loss registers a maximum at 0.015% of sugar. The loss over 180°-220° should be mainly due to the dehydrations of hexagonal aluminate hydrates. The maximum loss obtains at 0.015% sugar. 200°-300° covers the changes in 11Å tobermorite and hexagonal C₃A.6H₂O. In this region also there is a maximum around 0.015% but a slight minima at 0.06%. Cubic C₃A.6H₂O is known to show a peak around 320°-360°. We record a minimum in water loss in this region around 0.015% sugar. These data fit well with the fact that formation of the cubic, at the loss of the hexagonal form, is associated with loss of strength.

Conclusion

There is an increase in compressive strength of set cement paste with increase of sucrose concentration upto 0.015%. This may or may not be true if instead of neat cement paste, mortars were used. This beneficial effect seems to be due to the formation of more of strength augmenting phases like the tobermorite gel and hexagonal hydroaluminatate and less of strength decreasing phases like the cubic aluminate hydrate. Probably there is a different optimum concentration for each of the individual anhydrous cement compounds and the superposition of these leads to the rather complex dependence of compressive strength on concentration. Further studies of hydrated phases by X-ray and electron microscopy would be helpful.

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