*Discussion on Paper 6770**

Some investigations into the use of sugar as an admixture to concrete

by

R. Ashworth, B.Eng., A.M.I.C.E.

Mr K. H. Brittain (Cement Marketing Co. Ltd) wrote that as a research item the work described was an extremely interesting example of how knowledge on a property of concrete which had been partially understood for at least 45 years had progressed today. No research project was as extensive as might be wished for, and this was no exception.

42. In the choice of cement it was perhaps unfortunate that cements from a wider geological range of raw materials were not used. Inclusion of a white Portland cement might have been interesting. Apart from the low heat cement, which was not particularly typical of its group, there was no low C_3S, high C_2S cement.

43. No reference was made to air entrainment; it was anticipated that no extra air was entrained, but this was perhaps measured, and the figures would be useful. Referring to Fig. 6, it seemed unrealistic to carry out freezing and thawing tests on non-air-entrained specimens, although use of air-entrained concrete would have involved a much longer series of tests.

44. The effect of the admixture on other properties was also of interest; for example some hydroxy compounds were known to have a more damaging effect on bleeding than lignosulphonates.

45. The writer would like to have seen the figures in Table 4 continued for much longer than one year. It was not to be expected that specimens made with the first series concrete mix would be greatly affected in so short a period of immersion. It would be interesting to know which sand was used and if the water/cement ratio was nett or gross. The method of curing the specimens in Table 5 was not shown.

46. The extension of results from research laboratory to site was not easy. Experience with some other workability admixtures had shown that site labour was quick to appreciate the value of materials for purposes other than those intended by their management, and sugar would seem to have another ready use, apart from stirring a teaspoonful into the concrete! In addition, the dispensing of small amounts of admixture into concrete mixes was difficult. Adding a prepacked weight of sugar to a cubic yard of concrete sounded easy, but on experience gained by investigating complaints that concrete had failed to set, the writer could confirm that even reputable concrete makers had on occasions accidentally put four times as much admixture into concrete as they should have done. Admixtures for site use should be such that occasional and even severe misuse could only lead to limited adverse results. For site purposes the effect of the loam content of sand would have to be appreciated.

47. The cost quoted was of particular interest when compared with the cost of proprietary admixtures designed to achieve a similar purpose. If marketing was to be non-loss any admixture, when compared with this, would seem expensive. This was because of the costs of testing, packaging, transporting, and possibly distributing through an intermediary who was definitely making a profit on the cost of raw mat-

* *Proc. Instn civ. Engrs*, **31**, 129–145, June 1965.

erials. If it were possible to use a non-proprietary mass-produced article safely the economy would be appreciable.

48. The final point calling for comment was the saving in cement content. Provided that the water/cement ratio was below the limit suggested in B.R.S. Digest 13 Second Series,[18] or implied in Table 1 of CP116,[19] there could be no danger from the point of view of durability in taking advantage of compounds which reduced the water-requirement of concrete. The danger existed, however, that if the admixture dosage was unfortunately reduced, the water addition automatically made to give workability might lead to a less durable concrete. The dispensing of admixtures was too haphazard to be relied on in many circumstances, and except where heat of hydration was a particular problem, many engineers might feel that using the normal amount of cement and no admixture had attractions.

Dr A. López Ruiz (Rodio Testing Laboratories, Madrid) agreed with the spirit of the very interesting Paper. In 1957 he noticed by chance the important modifying action on concrete properties produced by the addition of small quantities of sugar. Since then he had continued to investigate the subject.[20, 21] The hypothesis and conclusions given in the Paper were very similar to those given in the writer's work.[22, 23]

50. In a few cases incompatibility between the sugar and Portland cements was observed. In these setting was so quick that the batch hardened in the mixer. This happened with cements of rather poor quality.

51. Chemical analyses had shown that in a mix of cement and a diluted solution of sugar, the concentration of this product decreased in the liquid phase and increased in the solid. It was also found by using the same procedure that the sugar content decreased with time in the cement/water systems, possibly by an oxidation process.

52. Some rigidity/time curves of water/cement pastes with different sugar contents were shown on Fig. 8. The tests indicated that the retarding effect increased

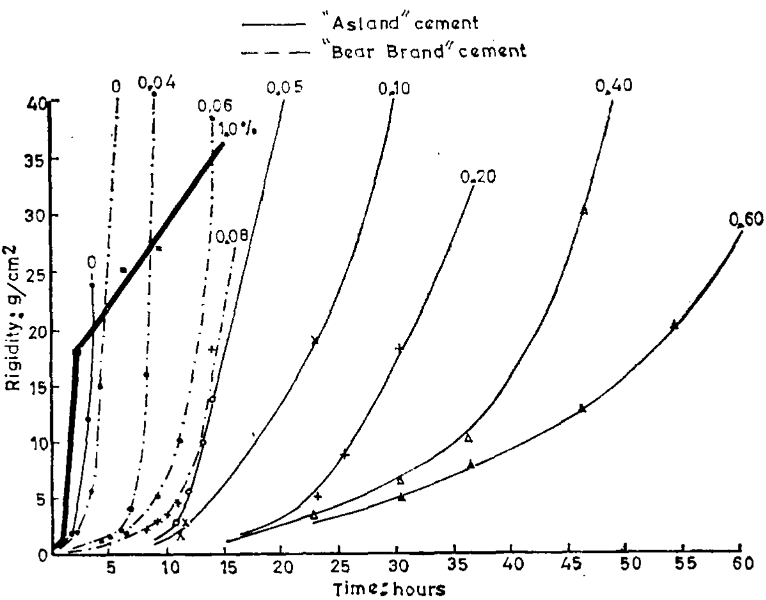

FIG. 8: RIGIDITY/TIME CURVES OF WATER/CEMENT PASTES WITH DIFFERING SUGAR CONTENTS

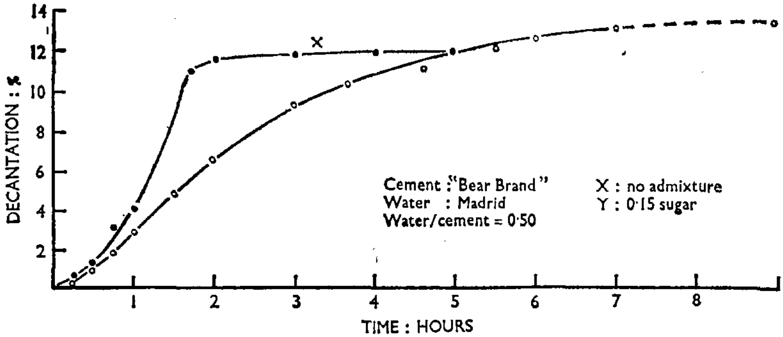

FIG. 9: DECANTATION/TIME CURVE OF WATER/CEMENT WITH AND WITHOUT 0·15% SUGAR

with the proportion of admixture. However, in one case with a sugar content of 1·0%, quick setting was obtained.

53. The decantation process of a water/cement system with 0·15% sugar was compared with the corresponding system without any admixture in Fig. 9. The tests indicated that the grains of cement with added sugar sedimented slower than those without admixture due to their better dispersion. However the final decantation was smaller in the latter case due to its quicker setting.

54. In order to learn the structural behaviour of small quantities of sugar added to concrete, two large diameter piles were cast. The concrete of one was mixed with 0·05% and the other with 0·12% of sugar. The concrete was poured under bentonite slurry through an 8-in. diameter pipe. During all the casting time the concrete had to have a fluid consistency in order to flow smoothly through the hole. The setting was followed by measures of the rigidity of the mortar obtained by passing the concrete through a 2 mm sieve.

55. The results were as follows:

(a) *Pile cast with concrete with* 0·05% *sugar as admixture.*

Diameter of pile: 1250 mm (50 in.)
Volume of concrete: 25 cu. m. (33 cu. yd)
Cement brand: 'X'
Water/cement: 0·53
Slump: 7 in.

Time for the mortar to obtain a rigidity of 10 g/sq. cm: 5 hours
28-day compressive strength: 215 kg/sq. cm (3050 p.s.i.)
1-yr compressive strength: 290 kg/sq. cm (4120 p.s.i.)

The concreting lasted 3½ hours. At the end of this time the concrete flowed out homogeneously through the iron frame, in very good condition.

(b) *Pile cast with concrete with* 0·12% *sugar as admixture.*

Diameter of pile: 1080 mm (43 in.)
Volume of concrete: 28 cu. m. (37 cu. yd)
Pile length: 30 m (33 yd)
Cement brand: 'Y'
Water/cement: 0·53
Slump: 7 in.

Time for the mortar to obtain a rigidity of 10 g/sq. cm: 8 hours
28-day compressive strength: 265 kg/sq. cm (3800 p.s.i.)
6-month compressive strength: 320 kg/sq. cm (4500 p.s.i.)
1-yr compressive strength: 350 kg/sq. cm (4980 p.s.i.)

The concreting time was a little longer than 8 hours and the whole process was normal.

(c) *Trench wall panel cast with concrete with* 0·085% *sugar as admixture.*

Thickness:	0·75 m (29·5 in.)	7-day compressive strength:	170 kg/sq. cm. (2420 p.s.i.)
Depth:	18·30 m (60 ft)		
Volume of concrete:	70 cu. m (92 cu. yd)		
Cement brand:	'Z'		
Water/cement:	0·57	28-day compressive strength:	225 kg/sq. cm. (3200 p.s.i.)
Slump:	7 in.		

The concrete was placed with tremie. Truck mixers were used. The concreting time was 7 hours. The entire operation was satisfactory.

56. At the present time the conclusions he had come to concerning sugar as a concrete admixture were as follows.

(1) Sedimentation tests had shown that sugar had a good dispersing effect on cement/water systems. However the final decantation was smaller in the systems without admixture due to its quicker setting.

(2) Rigidity/time curves of pastes and mortars showed that the retarding effect of sugar affected not only the standard setting time but also the whole setting process. This explained the improving effect of this agent on the workability of concretes and mortars.

(3) Though the effect was not equal with all cements, the addition of 0·06% sugar, besides producing an intense retarding effect, produced an increase in the compressive strength at 7 and 28 days. The strength was estimated to be 20–25% greater in comparison with the strength of concrete with an equal cement content and slump, but without the admixture.

(4) Sugar added to cement/water systems partially decomposed with time, which indicated the possibility that the whole might disappear.

(5) Sugar added to fluid concretes in proportions of 0·05% and 0·12% acted as an excellent retarder in casting large diameter piles under water. The concrete had shown a rigidity of less than 10 g/sq. cm. at 5 and 8 hours respectively when tested on the mortar obtained by passing the concrete through a 2-mm. sieve.

(6) With approximately 10% of the Portland cements tested, sugar in any proportion had proved incompatible. In one case this unfavourable result had occurred with a sugar content above 0·6%.

(7) The incompatibility of some Portland cements with sugar meant that close inspection was necessary and tests should be performed before using the admixture on site.

Mr C. J. Littlewort (Portland Cement Institute of South Africa) wrote that he was fascinated by the Paper in that here, right under one's nose so it seemed, was a cheap and readily available plasticizer capable of saving a fraction over 100 lb of cement per cubic yard on a 7000-lb mix at low workability.

58. Using an ordinary Portland cement of local manufacture complying with B.S. 12, the writer had tested this phenomenon for himself. He designed a mix at 0·4 water/cement ratio using the American Concrete Institute Method as adopted for use in South Africa by the Portland Cement Institute. He tested this mix at water contents of 320, 300, 280, and 260 lb/cu. yd by the 'driers' method, i.e. by adding calculated weighed amounts of stone and sand to the mix. At each of these water contents the slump and Vebe were measured and finally nine 4-in. cubes were made from the mix in its final condition, i.e. at 240 lb water/cu. yd. These cubes were tested, two at one day, two at three days, two at seven days, and three at twenty-eight days.

59. The test was then repeated using 0·05% sugar as suggested in the Paper. The results of these tests are shown in Tables 8 and 9.

60. The sugar mix had a slump of $4\frac{1}{2}$ in., as against that of $3\frac{1}{4}$ in. for the control, at 320 lb water/cu. yd. One could scarcely call this low workability. In the low workability range (plus ten seconds Vebe) the sugar mix was slightly stiffer than the equivalent control, but this was more likely to have arisen from experimental error than from any actual increase in stiffness.

61. This also applied to concrete strengths at three days and over, where the sugar mix appeared to be some 250 to 300 lb/sq. in. higher than the control. This was a difference of $3\frac{1}{2}$% and thus well within the limits of experimental accuracy for a test of this limited nature.

62. It would appear that the Author's findings were not, at all events, directly applicable to the South African cement used by the writer, although it conformed to B.S.12, since there seemed to be no significant difference in workability in the lower ranges or in strengths above three days between a concrete mix containing no sugar and one containing 0·05% sugar. The Author's comments on this apparent anomaly would be appreciated.

TABLE 8: CONCRETE MIXES AND WORKABILITY

Weights of materials (*lb/cu. yd*)				Workability			
				No sugar		0·05% sugar	
Water	Cement	Stone	Sand	Slump (*in.*)	Vebe (*secs*)	Slump (*in.*)	Vebe (*secs*)
260	650	1900	1379	$\frac{3}{8}$	14	$\frac{1}{4}$	15
280	700	1900	1284	$\frac{7}{8}$	7	1	$7\frac{1}{2}$
300	750	1900	1189	2	3	$2\frac{1}{4}$	$3\frac{1}{2}$
320	800	1900	1094	$3\frac{1}{4}$	2	$4\frac{1}{2}$	2

TABLE 9: CONCRETE STRENGTHS OF 4-IN. CUBES
(*lb/sq. in.*)

Age in days	1	3	8	28
No sugar	2760	5380	7350	8500
0·05% sugar . . .	1630	5410	7600	8790

Mr B. V. Harley (Ministry of Works and Communications, Nairobi) complimented the Author on his most informative and interesting Paper.

64. It had occurred to him that it would be extremely useful if such effects could also be obtained in soil-cement stabilization. Extensive soil stabilization work was in hand in Kenya and the additive used was nearly always cement. The setting of the cement limited the period in which the material might be worked. Also, high ambient temperatures, which markedly increased the rate of set and aggravated construction problems, were often encountered.

65. If such a cheap, convenient additive as sugar could be incorporated in the cement to give effects similar to those described for concrete, it would facilitate construction and reduce costs. For instance, less compactive effort would be required

to achieve the target densities. With set retarded for say 24 hours it would be possible to reprocess any areas, where this might be necessary, as with lime stabilization. Also, check tests on thickness, density, and shape could all be carried out, and remedial measures taken where necessary, without the necessity to work to a tight time schedule. If in addition to these advantages the rise in strength was rapid after the initial retardation, and there was even a gain in strength over comparable untreated mixtures at 7 days age, with no adverse side-effects, the use of cement/sugar mixes would be a most welcome technique. It would be interesting to know if any work had been done in this connexion, which would appear to offer a useful field of research.

66. In the limited time available he had carried out a few tests to obtain some initial information on the subject.

67. The materials used in the tests were refined white granulated sugar, ordinary Portland cement, and a sandy soil. Only one sample of soil and of cement was used. The soil-cement mixes all contained 4% cement by weight of the soil. The quantities of sugar added were expressed as a percentage by weight of the cement. All the tests were carried out in accordance with the relevant British Standards.

68. A British Standard (Proctor) compaction test was first carried out on the soil plus 4% cement, to determine the optimum moisture content. Specimens of 17% soil-cement were then moulded at this water content using 4% cement with nil, 0·05% and 0·20% sugar, also for each mix, using time delays of up to 24 hours between mixing and compaction. Compaction was carried out in 6-in. diameter C.B.R. moulds using the B.S. compactive effort. The dry densities obtained were measured, and the specimens cured in wax for 7 days after compaction and then tested for C.B.R. For a delay of 6 hours additional specimens were also made with a range of compactive efforts. The results obtained are given in Table 10 and are plotted in Figs 10 and 11.

69. For the mixes used with a constant compactive effort the dry density achieved decreased with increase in delay between mixing and compaction. The sugar/cement mixes gave results of a similar order to the mix without sugar, contrary to what was expected. The strengths obtained were roughly proportional to the densities achieved, with the sugar/cement mixes of higher strength than the corresponding untreated cement mix.

70. The sugar was mixed dry with the cement before adding the mixture to the soil. The soil was already close to o.m.c. and little extra water was added during mixing. In view of this it was thought that the effect of the sugar might be masked because it

TABLE 10: EFFECT OF SUGAR ON WORKABILITY AND STRENGTH OF SOIL/CEMENT

Compactive effort	Time after mixing (*hours*)	Dry density, (*lb/cu. ft*)			C.B.R. % (7-day cure)		
		Sugar added to the 4% cement					
		Nil	0·05%	0·20%	Nil	0·05%	0·20%
	0	107·2	107·1	106·7	100	124	118
B.S. Standard . . .	1	106·8	105·9	103·5	99	113	103
(Proctor)	3	105·3	102·3	101·0	80	91	76
	6	103·8	100·6	100·7	83	71	68
	24	92·9	93·3	91·9	36	36	36
½ B.S., Heavy (½ Mod. A.A.S.H.O.)	6	110·1	109·9	109·9	88	132	120
B.S., Heavy (Mod. A.A.S.H.O.)	6	112·5	113·3	113·3	94	104	112

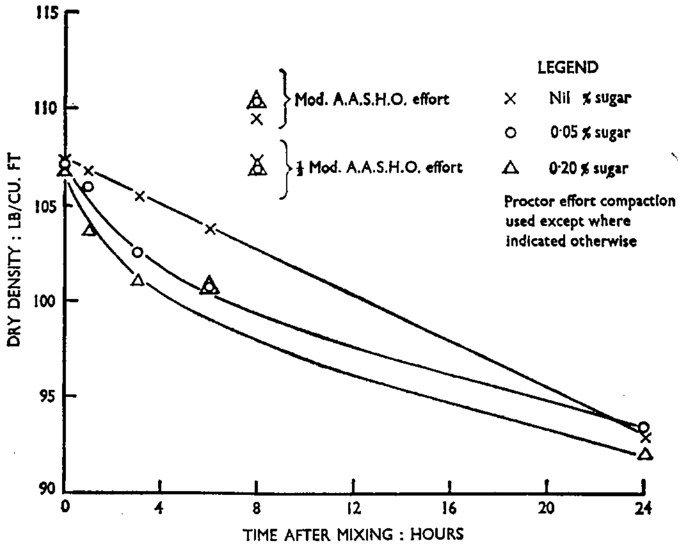

FIG. 10: EFFECT OF SUGAR ON WORKABILITY

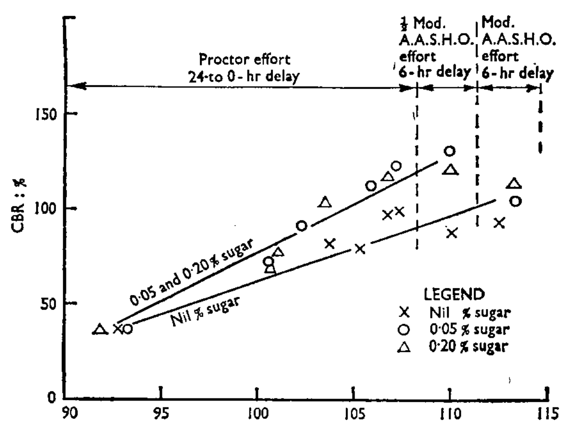

FIG. 11: DRY DENSITY/STRENGTH RELATIONSHIP

was not being distributed in solution in the way that would be expected with the richer, wetter mixes employed for concrete. To test the effect of the sugar on the setting time of the neat cement two sets of comparative mixes were made. In one set the sugar was mixed dry with the cement and in the other the sugar was added as a solution. The tests were carried out at the standard consistency for each mix. The results obtained are given in Table 11.

TABLE 11: EFFECT OF SUGAR ON SETTING TIME OF PORTLAND CEMENT

Cement admixture	Standard consistency %	State of sugar on mixing with cement			
		Dry		Solution	
		Setting time (*hours*)		Setting time (*hours*)	
		Initial	Final	Initial	Final
Nil . .	28·5	6·3	7·7	—	—
0·05% sugar	27·5	14·0	20·5	12·3	13·9
0·20% sugar	26·5	14·2	20·8	13·3	17·0

Note: 1. With the dry sugar mix the initial set took 3 hours from commencement on part of the sample to completion of the whole sample.
2. Final set conditions for the sugar mixes were maintained for many hours without apparent additional hardening.

71. Even these results contradicted in some respects those that had been expected. Retardation had taken place but there was little difference in effect between the 0·05% and 0·20% sugar mixes. The water demand of the mixes was, however, reduced for increased sugar content.

72. The setting times quoted were those at which set had occurred over the whole of the specimen. With ordinary cement this was simultaneous but the mixes with dry sugar were observed to behave differently. In this case the initial set did not take place simultaneously all over the specimen, although the mixing was very thorough. The set took three hours to complete from the time that one part of the sample had indicated initial set. The times quoted in the table were those at which the whole sample had reached that condition. The retardation with the dry sugar thus appeared to be more than that with the sugar solution additive. The range of times with the dry sugar might, however, represent variations due to the distribution of the sugar grains, whereas the sugar solution gave a more uniform condition.

73. The final sets took place in a more normal fashion but it was noted that, having obtained the 'final set' condition, they appeared to maintain this state for hours, without any apparent hardening.

74. In the time available it had not been possible to carry out further investigations into these phenomena, and it was unfortunate that such results as had been obtained in the limited tests, did not at first sight agree with the figures for concrete as well as had been hoped. This was possibly due to the surface characteristics of the soil particles influencing the properties in a manner not obtained with concrete aggregates. To overcome such masking effects higher sugar contents might be necessary. However, more work on these lines would appear to be profitable and it was hoped that the figures presented would be of interest.*

* This contribution is presented with the permission of the Permanent Secretary to the Ministry of Works, Power, and Communications, Kenya.

The Author expressed gratitude for the widespread interest shown in his Paper, both in the written discussion and in other communications which he had received privately. As Mr Brittain had commented, no research project was ever as extensive as might be wished for, but it was always difficult to know where to draw the line, especially in the field of concrete technology where the results were often not available until some time after the completion of the experimental work.

76. Dealing first with the queries raised by Mr Brittain, the concrete was in all cases non-air-entrained and no measurements of air content were made. As far as the Author was concerned, this did not in any way reduce the value of the freezing and thawing tests since the results were directly applicable to the majority of concrete work carried out in Great Britain. In fact, had an air-entrained mix been used for these experiments the results might have been considered to have had less practical value.

77. The sand used in the investigations differed for all three series of tests, both in grading and in particle shape. Typical gradings are given in Table 12. The Norcott and Stretton Cone sands were of rounded or irregular particle shape whilst the Croxden sand was distinctly angular in character. The water/cement ratio was in all cases based on the total water content of the mix with the aggregates in the air-dried condition. All specimens, excepting those cured in water during the first series of tests, were cured in moist air.

TABLE 12: SAND GRADINGS FOR LABORATORY INVESTIGATIONS

B.S. sieve	Cumulative percentage passing		
	Norcott sand (first series)	Stretton Cone sand (second series)	Croxden sand (third series)
3/16 in.	93	99	94
No. 7	88	85	82
No. 14	85	73	73
No. 25	76	59	66
No. 52	38	15	35
No. 100	7	2	6

78. With regard to the extension of laboratory investigation to site practice, the dispensing of any admixture did present some difficulty and some form of automatic dispensing mechanism seemed advisable. In suggesting a sugar content of 0·05%, the Author had taken account of the effect of an accidental overdose, and Fig. 1 showed that four times the specified amount of sugar would still give concrete of satisfactory strength, although there might be some inconvenience in the stripping of formwork.

79. Dr Ruiz's comments on the Paper were very encouraging since they illustrated once again the outcome of similar results from two entirely independent and unrelated pieces of research. The Author had not experienced any quick setting of the concrete resulting from incompatibility between the sugar and the cement, but it appeared that this only occurred when using cements of rather poor quality which presumably would not have conformed to B.S.12.[24] The application of the results to full-scale experiments with large diameter piles was particularly interesting and was an example of how a cheap retarder might be usefully employed in practice.

80. Mr Littlewort's contribution seemed to show the danger of drawing firm conclusions from a limited number of tests. However, when one looked at Mr Littlewort's own experiments it appeared that his comments were based essentially on the results obtained from two single mixes—one containing sugar and one control

mix—to which successive amounts of aggregate had been added to vary the workability. Bearing in mind the variations in both workability and strength which were often found between nominally identical concrete mixes, even under the strictest laboratory control, it seemed unwise to offer any comments on the apparent anomaly between the two sets of results and the Author could only suggest a more extensive investigation covering a wider range of water/cement and aggregate/cement ratios to test the validity of his findings in relation to South African cements.

81. The possible use of sugar as an admixture in cement-stabilized soil was a logical extension of the Author's work, and the information supplied by Mr Harley was thus of considerable interest. Certainly, from the figures given, there was no evidence of sugar acting as a retarder in soil-cement mixtures, although one suspected that the loss of dry density could be attributed largely to loss of moisture by evaporation rather than to hydration of the cement. If this were so, the mixes containing sugar could not have been expected to behave very differently from the control mix. The increased C.B.R. value generally obtained with the mixes containing sugar was perhaps indicative of the more efficient dispersion of the cement particles throughout these mixes and further work along these lines would appear profitable.

References

18. *Concrete Mix Proportioning and Control, A.* Bldg Res. Stn Dig. No. 13. 1961.
19. British Standards Institution. *The Structural Use of Precast Concrete.* B.S. 116. London, British Standards Institution, 1965.
20. López Ruiz A. Un procedimiento perfeccionado para la obtención de un plastificante del hormigón. Patente española de invención No. 239.501. Jan. 1958.
21. López Ruiz A. Un procedimiento para mejorar las propiedades del cemento destinado a la construcción, Patente española de invención No. 296.866. Feb. 1964.
22. López Ruiz A. Efecto de la adición de pequeñas cantidades de sacarosa al agua de amasado de hormigones de cemento portland. *Quím. Ind.*, 1963, **10** (Sept.–Oct.), 154–158.
23. López Ruiz A. Nuevas aportaciones sobre el efecto de la adición de pequeñas cantidades de sacarosa al agua de amasado de hormigones de cemento portland. *Rev. Obr. públ.*, **113** (Nov.) 931–940.
24. British Standards Institution. *Portland cement (Ordinary and rapid-hardening).* B.S.12. London, British Standards Institution, 1958, p. 38.