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The Economic Aspects of Admixture Use

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Abstract

The paper describes four areas where concrete chemical admixtures have made an economic impact on the concrete industry. The development of the use of air entraining agents for highways, runways, and parking garages after their accidental discovery is described. The use of water reducing agents to effect economies in mix design is discussed, together with factors influencing the degree by which these economies can be realized. The application of superplasticizers in reducing the labor involved in the handling, placing, and finishing of concrete is presented. Lastly, the use of accelerators to reduce the extended setting time of concrete for flatwork at lower ambient temperatures is outlined. © 1998 Published by Elsevier Science Ltd. All rights reserved.

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INTRODUCTION

The admixture industry has made a major impact on the economics of the concrete industry in a variety of ways. It has enabled the development of specific applications in the concrete industry, allowed concrete ingredients to be used more cost effectively, assisted in new labor-saving procedures, and permitted concreting to continue at low ambient temperatures. Examples of each of these are discussed in this paper.

DEVELOPMENT OF THE USE OF CONCRETE FOR PAVEMENTS

The observation during the 1930s that certain stretches of roads in the northeast states of the USA were more able to withstand the effects of freeze–thaw conditions and the presence of de-icing salts than other roads in the region[1] was a pivotal example of how admixtures led to the wider application of concrete in a specific area. An investigation revealed that the more durable roads were less dense and that the cement had been obtained from a mill where tallow had been used as a grinding aid. It was concluded that the beef tallow had functioned as an air-entraining agent and had enhanced the durability of the concrete. This led to a more controlled investigation, and in 1939 an air-entrained concrete carriageway was intentionally produced by the New York Dept. of Public Works.[2] Subsequent developments by the admixture industry to produce neutralized wood resin and synthetic surfactant-based air-entraining agents allowed air of the correct bubble size and quantity to be reliably and reproducibly entrained. This has led to many thousands of kilometers of concrete highways, aircraft runways, and parking lots to be built over the following 50 years in geographical areas where freeze–thaw conditions are experienced. In addition, the concrete can be improved in other respects, such as enhanced cohesion, by the use of air-entraining agents.

What is remarkable is that the enhanced durability can be obtained at such a low (or even no) increase in cost of the concrete. A consideration of the mix design aspects of air-entrained concrete[3] is shown in Table 1, where it can be seen that because of the possibility of water reduction due to the higher paste content of the entrained concrete and the increased yield due to the air content, the total cost of the air-entrained concrete can be lower than the plain concrete, even though the cement content is higher. This is not always the case, however, as many factors influence the final mix design.

Table 1. Mix design/cost data of air-entrained mixes having similar compressive strengths

	Cost	*Plain mix (lbs/yd³)*	*Air-entrained mix (6.5%) (lbs/yd³)*
Cement	$0.040/lb	500	530
Aggregate	$0.005/lb	3090	2810
Water		275	291
Air-entrainer	$0.010/oz	0	6.625 oz
Cost/yd³ ($)		35.45	35.32

This is a good example of where the initial serendipity of the discovery of the benefits of chemical additions to concrete was followed by a scientific investigation and the opportunity seized by the admixture industry to develop reliable and effective materials to meet the requirements. In this way a major applicational area for concrete was developed.

CEMENT SAVINGS USING WATER REDUCING AGENTS

This concept of obtaining an economic advantage from the use of admixtures is probably the best known and widely practiced world-wide throughout the world-wide concrete industry. The diagram shown in Fig. 1 is well known[4] and shows how 'corresponding mixes' containing different cement contents can have the same workability, strength, and durability characteristics by the use of water reducing admixtures in the lower cement content mix, which can have even improved properties in terms of drying shrinkage, creep, and thermal stresses.[5] However, in practice, where the real cost savings come down to the difference between the cost of the admixture and the savings in the concrete ingredients, things are sometimes not so simple, as the writer learned some years ago. A customer introduced the 'three-point' method of evaluating the effectiveness of water reducing agents (WRAs) where three concrete mixes are designed at three different cement contents, with and without the presence of a WRA at the same initial slump. The results that were shown to the writer are shown in Table 2 and graphically in Fig. 2. Taking corresponding mixes containing 500 lbs cement/yd^3 and 474 lbs cement/yd^3 plus 4 oz/100 lbs cement of a WRA, both having a 28 day compressive strength of 5500 lbf/in^2, it can be seen from the cost analysis in Table 3 that there are no savings in net cost. Thankfully, the price of cement has risen over the intervening years whilst that of admixtures has remained more or less the same, so an updated cost comparison looks a little better today. The point is, however, that with these particular mix ingredients, only a 5% water reduction was obtained with a relatively expensive admixture, which negated the potential cost savings. It should also be noted that both the ASTM[6] and British Standards[7] have 5% as the minimum water reduction, so many products could have this sort of performance level. For a complete picture, the following points need to be considered.

(a) Water reduction; the example given above was based on a 5% water reduction. Higher reductions can be obtained, and the effect of

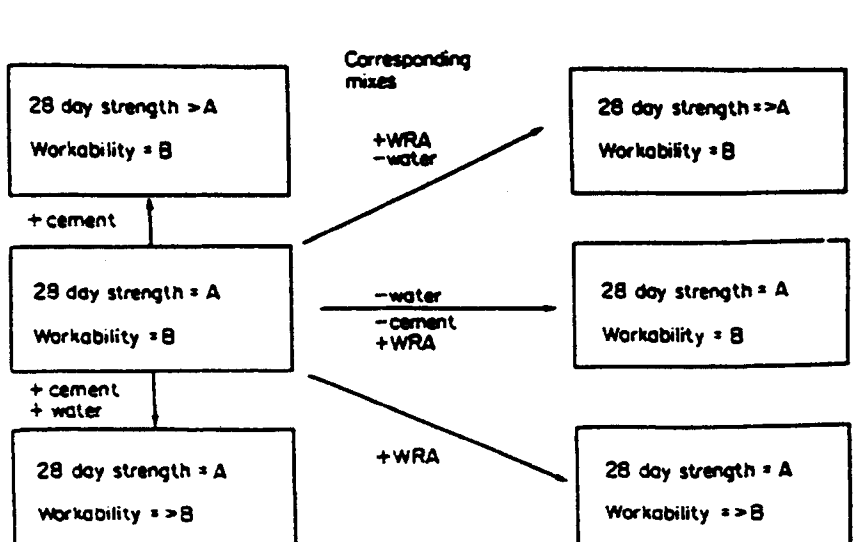

Fig. 1. The concept of corresponding mixes.

Table 2. 'Three-point curve' evaluation of a WRA

Admixture	*Cement factor (lbs/yd³)*	*Water content (lbs/yd³)*	*W/C ratio*	*Unit weight (lbs/ft³)*	*28 day compressive strength (lbf/in²)*
None	400	279	0.71	148.3	3791
(Control)	500	275	0.54	150.4	5466
	600	269	0.45	150.8	6526
4 oz/100 lbs	400	264	0.67	147.5	4153
Cement	500	267	0.53	150.2	5815
WRA	600	259	0.43	150.8	6851

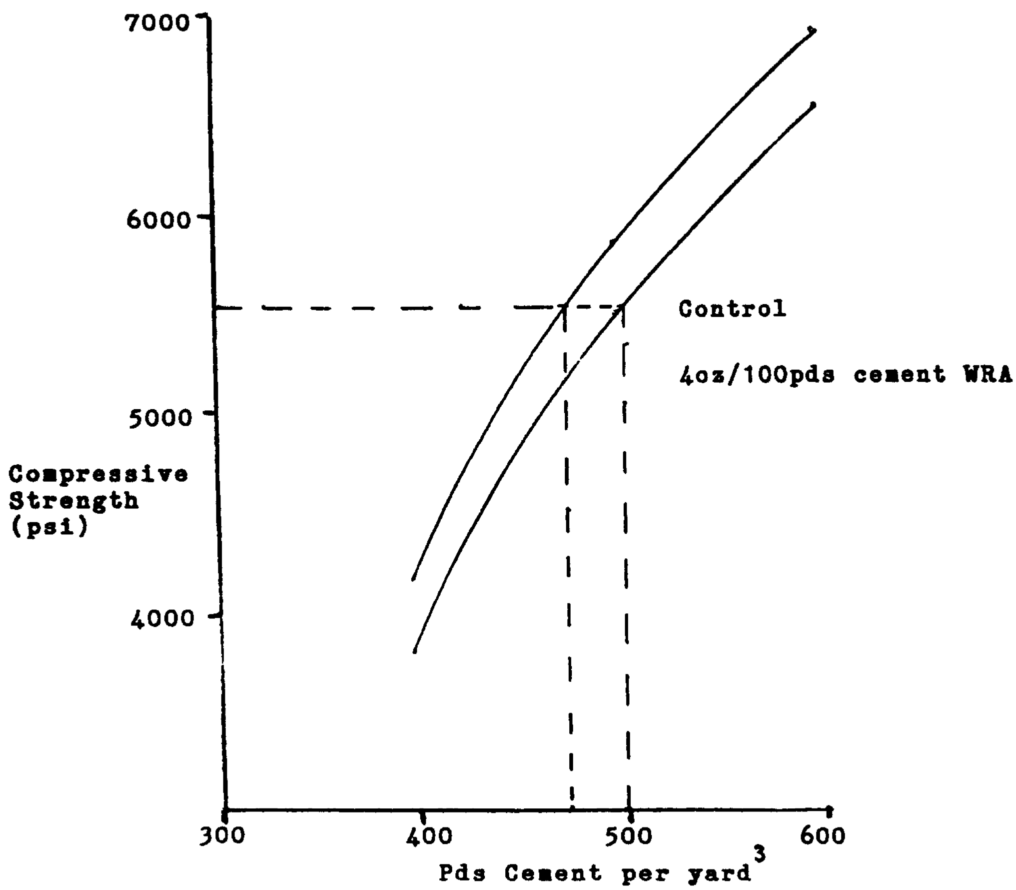

Fig. 2. Three-point curve.

Table 3. Cost comparison with and without admixture

		Blank	*Admixture*
Cement	(lbs/yd³)	500	474
Stone	(lbs/yd³)	1850	1850
Sand	(lbs/yd³)	1360	1400
Water	(lbs/yd³)	280	265
Admixture	(oz)	0	18.96
Cement	($49.00/2000 lbs)	12.25	11.61
Stone	($12.50/2000 lbs)	11.56	11.56
Sand	($10.00/2000 lbs)	6.8	7
Admixture	($2.80/128 oz)	0	0.41
Cost/yd of concrete ($)		30.61	30.59

this on the 'three-point' curves for different types of water reducing admixture (lignosulfonate, multicomponent, and mid-range) are shown in Fig. 3, and the corresponding mixes and cost analysis are shown in Table 3. It should be noted that whilst different cements may alter the shape and position of the curve for the plain mix, the WRA-containing curves invariably take the form illustrated in Fig. 3, with a higher water reduction at the higher cement contents, unless there is a significant difference in the air entrained by the different mixes. The amount of water reduction obtained is influenced by the following main factors.

(i) Cement characteristics; although large differences in the performance of WRAs with different cements have been observed, to date there is no reliable way of forecasting behavior from cement composition, although a major project in this respect is planned.[8] It has been noted,[9] however, that higher C_3A levels reduce the effectiveness of WRAs, possibly by adsorbing part of the active material and preventing it from playing a role in the deflocculation of the cement particles, and there is some information available on the role of SO_4 level and type, and fineness of cement.

(ii) Admixture composition; it is obviously true that a higher solids content will perform more effectively than a lower one, but it has also been observed that the different chemical types of water reducing admixture have different degrees of effectiveness, and this is also cement dependent.[10,11]

(iii) Admixture dosage; the experience of the author and others[11] is that there is a straight line directly proportional relationship between the dosage of a WRA and the water reduction obtained, i.e. double the dosage gives double the water reduction over the ranges normally encountered. This leads to the interesting conclusion (certainly to the admixture supplier) that the higher the dosage that can be tolerated from a retardation point of view, the greater will be the cost savings. This can be illustrated by referring back to Table 4, where it can be seen that if we double the dosage of the lignosulfonate WRA admixture costing $1.50 per gallon from 5 oz to 10 oz per 100 lbs cement, the water reduction would be doubled from 5%

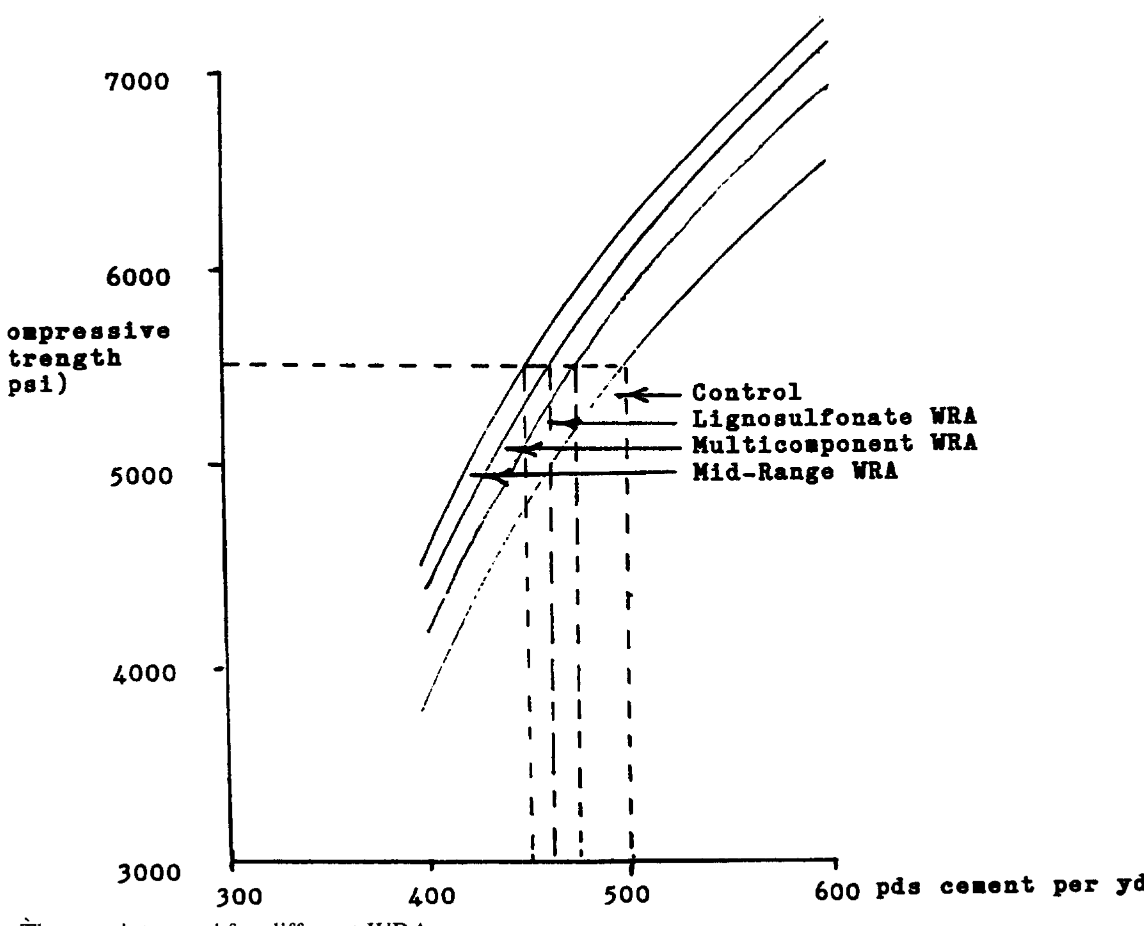

Fig. 3. Three-point curve' for different WRAs.

Table 4. Cost savings analysis for various water-reducing admixtures

Admixture type	*None (control)*	*Lignosulfonate*	*Multicomponent*	*Mid-range*
Admixture dosage (oz/100 lbs cement)	0	6	6	10
Water reduction (%)	0	5	7.5	10
Cement (lbs/yd^3)	500	475	463	450
Stone	1850	1850	1850	1850
Sand	1431	1443	1448	1453
Water	280	266	259	252
Admixture	0	28.5	27.8	45
Cement @ $75/2000 lbs)	18.75	17.81	17.36	16.88
Stone @ $8/2000 lbs)	7.4	7.4	7.4	7.4
Sand @ $8/2000 lbs)	5.72	5.77	5.79	5.81
WRA lignosulfonate @ $1.50/gallon		0.33		
WRA multicomponent @ $2.50/gallon			0.54	
WRA mid-range @ $2.80/gallon				0.98
Total cost/yd^3 ($)	31.87	31.31	31.09	31.07
Cost saving/yd^3 ($)	0	0.56	0.78	0.8

to 10% and the net saving would increase from $0.56 to $1.10/yd^3. In the case of most lignosulfonate-based WRAs, this exercise is probably hypothetical, since the degree of retardation at the higher dosage would probably be unacceptable, but it is certainly worth going up in 1 oz/yd increments to find the optimum level. Alternatively, in the past 4 years, the mid-range WRAs have been developed to allow higher dosages, and hence water reductions (8 to 12%), without dramatic increases in setting times.

(b) Admixture price; this is clearly a factor as far as a specific type of WRA admixture is concerned (for example a lignosulfonate at a given solids content). However, it is cost effectiveness that is important, as clearly illustrated in Table 4, where the most expensive product at the highest dosage level has resulted in the lowest per yard cost.

To summarize, the cost saving that can be effected using WRAs can be very significant (at $0.80 per yard this is $200 million per year in the USA) as long as care is taken in the selection of a cement that is compatible with WRAs (or vice versa), that as high a dosage as possible is used, and that in negotiating a price for the admixture, solids content as well as per gallon price should be a consideration.

THE USE OF HIGH RANGE WRAs (SUPERPLASTICIZERS) FOR SELF-COMPACTING CONCRETE IN FLATWORK

Superplasticizers have been in use in Japan and Europe since the 1960s but are still incorporated in less than 5% of all concrete. In view of the high dosages used (four to five times that for normal WRAs), this is an important part of the admixture business and has led to improvements over the original naphthalene- and melamine-based products, particularly in the area of slump retention with the development of acrylate systems.[12]

However, the advantages for using superplasticizers is not well understood by the concrete industry, and whilst in the limited market of high performance concrete an on-cost of $5.00 or more can be justified, it is more difficult to demonstrate how this sort of cost can be recovered for regular concrete produced every day by the industry. One study[13] did demonstrate very powerfully that the use of superplasticizers in standard 3000 lbf/in^2 concrete for residential slabs on grade could result in significant labor savings. This well-documented and recorded work involved the placing of about 20 slabs using the normal concrete and 20 slabs using concrete that had been brought to a high workability condition by the use of a melamine-based superplasticizer. The properties of the resultant concrete and the labor requirements at each stage of slab production (chute, placing, screeding, jitterbug, floating) were noted. Table 5 summarizes the percentage savings in labor time for these procedures. The report concluded that the standard placing crew could be reduced from ten to five or six with some increase in hours worked, or the crew headcount could be maintained with an increase in the number of slabs produced per day. The overall labor savings were 33% and the quality of the concrete was improved in terms of compressive and flexural strengths and flatness.

THE USE OF ACCELERATORS FOR REDUCING SETTING TIMES

Accelerators are often used year round to shorten the setting time and to accelerate the early strength development of concrete, particularly in a factory setting, for example concrete products such as blocks and pavers. However, the largest and most common use is to compensate for the extension of setting times of ready-mixed concrete due to lower ambient temperatures in winter. The effect that temperature has on the setting time of concrete is well documented,[14] but it still seems to come as a surprise to many in the industry in fall when temperatures drop and finishing crews are waiting for the concrete to set. For each drop of 18°F (10°C), the setting time is doubled. This is illustrated by the control curve in Fig. 4, where it can be seen that a change from a summer 77°F (25°C) to a fall or winter 41°F (5°C) could increase the setting time from 4 h to 16 h!

Table 5. The savings in labor times at each stage of production of residential concrete slabs using superplasicizers

Activity	*Savings in labor time (%)*
Chute	54
Place	39
Screed	20
Jitterbug	22
Float	15
Combined	33

The most commonly used accelerator is calcium chloride, and where there is a requirement for the accelerator to be chloride free, products are available based on calcium nitrate, calcium nitrite, calcium thiocyanate, and calcium formate. However, none of these chloride-free products are as cost effective as calcium chloride.

There are usually considered to be five ways in which the setting time can be reduced when lower ambient temperatures prevail: the cement content can be raised by about 100 lbs/yd^3, which may shorten the setting time by 2–4 h but cannot compensate for the sort of conditions discussed above; use type III cement, which has a similar effect as increasing the cement content but at a higher cost; raise the temperature of the concrete ingredients if the required equipment is available, and which, if combined with

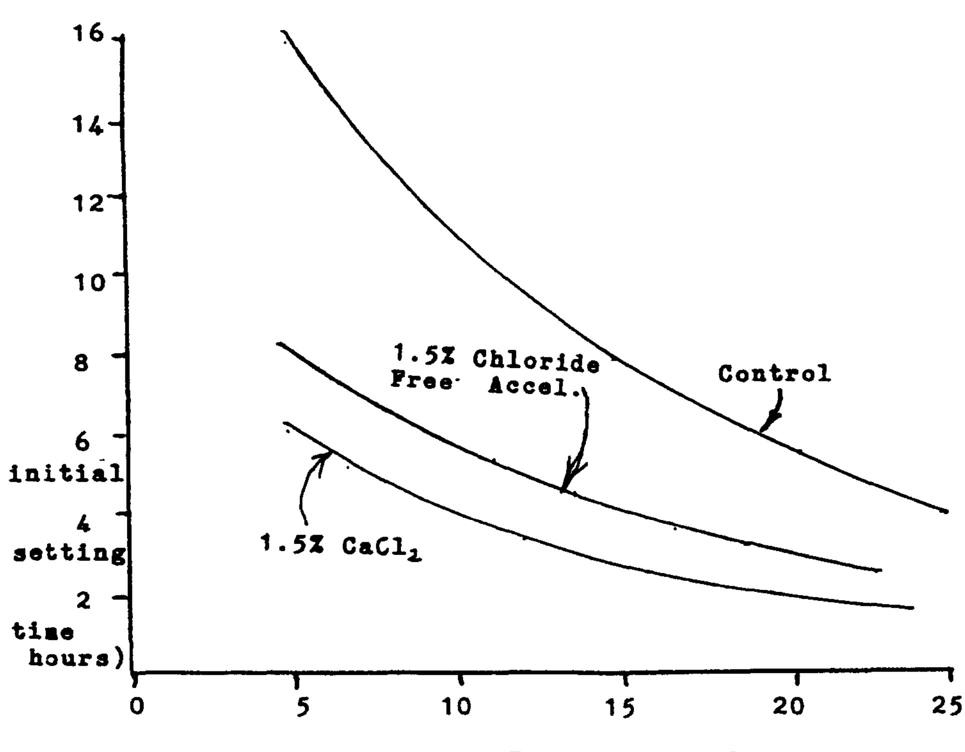

Fig. 4. Effect of temperature on setting time with accelerators.

Table 6. Cost and effectiveness of various methods of compensating for low ambient temperatures

Alternative	*Approx. cost/yd ($)*	*Effectiveness*
Raise cement content	3.00	Shorten initial setting time by 2–4 h
Use type III cement	10.00	Shorten initial setting time by 2–4 h
Heat concrete ingredients	4.00	Bring initial setting time back to normal
Use 1.5 wt% calcium chloride	3.00	Equivalent to a temperature increase of 15°C (27°F)
Use 1.5 wt% chloride-free accelerator	6.00	Equivalent to a temperature increase of 10°C (18°F)

heated blankets at the job site, brings the setting times back to normal levels; use a chloride-free accelerator, which at higher dosage levels will be equivalent to an 18°F (10°C) increase in temperature; use a chloride-containing accelerator, which would be the same as a 27°F (15°C) increase in temperature. These latter two scenarios are illustrated in Fig. 4, and the approximate costs of each alternative are given in Table 6. The most cost-effective system is usually a 1.5 wt% cement dosage of calcium chloride: this is satisfactory for anything but the most severe of conditions, when the heating alternative should be used (or a combination of both).

CONCLUSIONS

There are many ways that the admixture industry has contributed to the economics of the concrete industry, and this paper has described four of them. There are others, such as allowing the use of microsilica for high performance concrete, admixtures for the re-use of washout water, pumping aids for the more efficient placing of concrete, etc., and together they are substantial and have made a major contribution to the acceptance of concrete as a construction material of choice.

REFERENCES

1. Jackson, F. H., ACI J., **14** (1994) 509
2. Della-Libera, G., *Proceedings of the International Symposium on Admixtures for Mortar and Concrete*, Brussels, 1967, p. 142.
3. Dodson, V., *Concrete Admixtures*. Van Nostrand Reinhold, USA, 1990, p. 155.
4. Rixom, M. R. & Mailvaganam, N. P., *Chemical Admixtures for Concrete*, 2nd edition. E&FN Spon, UK, 1996, p. 2.
5. Collepardi, M., Water reducers/retarders. In *Concrete Admixtures Handbook*, 2nd edition, ed. V. S. Ramachandran. Noyes Publications, USA, 1995.
6. ASTM C494.
7. British Standards 5075: Part 1.
8. Rixom, M. R., Letters to the editor. *Conc. Int.*, **18** (1996) 9
9. Burk, A. A. *et al.*, *Proceedings of the 2nd International Conference on Superplasticizers*, Ottawa, Canada, 1981.
10. Rixom M. R. & Mailvaganam, N. P., *Chemical Admixtures for Concrete*, 2nd edition. E&FN Spon, UK, 1986, p. 18.
11. Dodson., V., *Concrete Admixtures*. Van Nostrand Reinhold, USA, 1990, p. 45.
12. Tanaka, Y. O., *et al.* (1996).
13. Zommo, M. & Henry R. L. *Conc. Int.*, February (1982) 31–35.
14. Burg, R. G., Concrete technology today. *PCA*, December (1996) 5–7.