SUPER PLASTCIZER: CEMENT: CONCRETE

Use Of Super Plasticizers In Cement Concrete: Present Status And Future Prospects In India

Irshad Masood and S.K.Aggarwal, Central Building Research Institute, Roorkee

The addition of certain substances to concrete mixes has been found to result in the reduction of water content for preparing a workable concrete. The materials used to increase the workability are many, like lime, foaming agents, sodium silicate and the surfactants etc. The addition of one such substance, the plasticizer to the concrete results in better workability and higher strength than the control concrete. However, the above materials have effects of a low order. There are some other substances such as glucose, Na-gluconates, Ca and Na-lignosulphonates, salicylic acid, hydroxy acids, carbohydrates, borates, phosphates of Pb, Zn, Cu etc. which are also capable of reducing water requirement to the order of 10-15 percent. Higher dosage of these may result in further reductions but the properties of the concrete may get adversely affected.

To achieve still higher reduction some organic materials have been developed during the last two decades which are called super plasticizers. Such substances are capable of reducing water contents to the order of 30 percent and at the same time result in improvement in the desirable properties of concrete. Although such materials have been known since 1940, they have been used for purposes other than concrete. Their use for concrete began in 1960 in Germany and Japan and later on these substances got introduced in Europe and America in 1970. In the initial stage the salts of polymerised naphthalene formaldehyde sulphonate were introduced; later on other formulations found their way. Now super plasticizers constitute a class of their own and can be classified into four groups on the basis of their chemical composition:

a) Sulphonated melamine formaldehyde condensate (SMF)
b) Sulphonated naphthalene formaldehyde condensate (SNF)
c) Modified lignosulphonates (MLS)
d) Others including sulphonic esters, carbohydrates esters, salts of organic hydroxycarboxylic acids etc.

A number of advantages in concrete behaviour have been found by the researchers with the use of super plasticizers such as (a) the production of high workability for easy placement of concrete even in complicated situations as well as those bearing complex reinforcements, (b) high strength concrete with less water content but with normal workability, and (c) concrete with normal strength using lesser content of cement etc. The addition of super plasticizer is said to help in avoiding adverse effects on shrinkage, durability etc. in concrete with higher cement contents for high strength by reducing the water cement ratio and allowing slow stiffening.

Types And Pattern Of Use

A number of studies on the use of different types of super plasticizers in concrete to enhance one or the other property have been reported mostly in the developed countries. SMF and SNF based super plasticizers are cited for use in concrete extensively in the literature.

Rixom and Waddicor(1) and Malhotra and Malanka(2) compared the behaviour of melamine, naphthalene and lignosulphonate super plasticizers and found that all behaved well; 0.6% SMF or MLS produced similar effect as obtained by 0.4% SNF by increasing the slump from 50-260 mm.

The dosage required to obtain a particular slump depends on the initial slump, while the slump value increases with the increase in amount of super plasticizer in concrete(3) but to a limited extent. The slump is generally found to be affected by the type and content of cement used(4). Water reduction in concrete with use of super plasticizer with all types of cements does occur but the extent of reduction is not the same(5). Excessive dosage of super plasticizer in concrete tends to promote segregation of fresh concrete and subsequently results in an increase in the heterogeneity of hardened concrete with depth(6). However, on keeping the slump, water-cement ratio and fine aggregate percentage constant, super plasticized concrete behaves similar to air entrained concrete with regard to resistance to segregation and homogeneity of hardened concrete. Kishitani et el(7) have shown that a flowing concrete obtained by using SNF based super plasticizer had no adverse effects on the properties of hardened concrete except inducing some increase in bleeding of fresh one, whereas the placeability of concrete was observed to be twice as easy as that of control concrete in addition to improved surface appearance and high strength.

A study by Brooks et.al.(8) on strength, elasticity, creep, shrinkage, swelling etc. of water cured and steam cured concrete made with a rapid hardening portland cement with and without SMF super plasticizer yielded very interesting results. The continuously water — cured specimen showed strength and modulus of elasticity in increasing order but in case of exposure to drying at the age of two days, the super plasticized concrete showed higher shrinkage and creep and constant stress strength ratio and at later ages gave lower compressive strength and modulus of elasticity. Steam curing for six hours and then storing in water results in higher initial compressive strength than those stored continuously in water. At higher ages (407 days) the strength of steam cured and then water cured specimens were 7 and 14 percent lower than with continuous water curing for control and admixtured concrete respectively.

Tokuda et al.(9) performed studies on rich mix concrete using three super plasticizers namely polycyclic sulphonate, highly polymerised triagin and b-naphthalene acids, to improve drying shrinkage, thermal diffusivity and coefficient of thermal expansion. The choice and suitable dosage of super plasticizer resulted in reduction of unit water content and also resulted in the decrease in cement content which may be of great help in designing massive concrete structures of comparatively rich mix concrete for preventing shrinkage and thermal cracks.

Flyash Substitution In Cement — Concrete

Although a large number of workers have studied (10-15) the use of flyash in concrete but only a few have tried to obtain high strength concrete with replacement of cement by flyash and incorporation of super plasticizer.

Dransfield (16) described a case history where 20 per cent cementitious material was replaced by pfa (pulverised fuel ash) and use was made of super plasticizers which resulted in water reduction of the order of 20-25 per cent and the strength increase of 140-155 per cent at 28 days and that was maintained to the order of 120-135 per cent after three years. Eriksen and Christensen(17) experimented on increasing the flyash content in concrete by using super plasticizer NSAP and showed that a reduction in cement content from 450-500 kg/m^3 to 270 kg/m^3 is possible by increasing the flyash content to as much as 130 kg/m^3. It was also found that the combined use of flyash and super plasticizer (cemix) may be exceedingly beneficial from strength point as water cement ratio is reduced, since the heat evolution is reduced in such conditions. Malhotra (18) also showed that the combined use of flyash and super plasticizer allows the manufacture of semi-light weight concrete of 1835-1961 kg/m^3 with strength of the order of 30 and 40 MPa at 1 and 3 days respectively. Nagataki et al. (19) found that incorporation of 45 per cent flyash and super plasticizer in cement concrete gave autoclaved concrete of good strength properties. Mukherjee et al. (20) also established that high strength concrete can be obtained by using higher percentage of flyash in presence of super plasticizer. Stuart et al. (21) showed that high replacement of cement by flyash in mortar in presence of super plasticizer does not result in an appreciable increase in strength.

Precast Units

Use of super plasticizers for obtaining good performing concrete units have been advocated by a number of workers. Aignebeiger and Kern (22) found that by the use of SMF super plasticizer in high performance concrete for blocks, pipes and extruded concrete products, proper placing and compacting can be achieved at almost any water cement ratio. The water cement ratio is reported to be reduced in this case but workability maintained and the strength increased. Higher dosage of SMF resulted in increasing the workability with reduction in water-cement ratio but gave higher strength concrete. Even with the use of lower quality of cement in the presence of SP the results obtained have been as good as with use of SP without lowering the quality of the products. There is little information on the use of super plasticizer for no slump or zero slump concrete. Pfeiffenberger and Ray (23) investigated the use of various dosages of SMF based super plasticizer for producing extra higher strength concrete blocks and found that 3 per cent addition showed best performance. One point for further study was raised i.e. whether a mix of 1:7 cement aggregate could be altered to leaner mixture and would it be possible to lower the curing temperature and machining time etc.

Similarly Mureta et al. (24) showed that it is possible to produce and utilise high strength concrete for prestressed concrete piles, rail piers etc. The production of high strength concrete can make it possible to reduce the cross section of the structural members and these can replace steel structures. In this study various cement contents (450-500 kg/m^3), two types of super plasticizer (SNF and SMF), two slumps (140 mm and 80 mm) for insitu cast concrete and prestressed concrete respectively were used. Curing was done in autoclave, steam and ordinary temperatures. A 60 MPa strength concrete was [illegible] tained with water-cement ratio of [illegible] per cent. The particle size distribu[illegible] of cement was found to greatly [illegible] ence the consistency of high stre[illegible] concrete with very low water [illegible] ratio.

Ramakrishnan et al.(25) [illegible] the performance characteristics [illegible] per plasticized fibre reinforced conc[illegible] and found that fibre content ma[illegible] increased with good bond and impro[illegible] ment in flexural strength, load carry[illegible] capacity and ductility.

Collepardi and Corradi (26) [illegible] that addition of super plasticizer [illegible] concrete mix helps improve the adhe[illegible] of concrete and steel and that the [illegible] strength with normal bar increased [illegible] 1.2 to 3.5 MPa while for twisted ba[illegible] increased from 15.0 to 27.5 MPa after [illegible] days curing.

Efficacy In Presence Of Other Additives

The addition of certain oth[illegible] constituents alongwith the sup[illegible] plasticizers has been found to influ[illegible] the efficacy of the super plasticizer [illegible] the properties of the resultant concr[illegible] Collepardi et al.(27) used SNF sup[illegible] plasticizer in a concrete containing [illegible] expansive agent to reduce the dry[illegible] shrinkage and found that a le[illegible] expansive agent would be required [illegible] shrinkage compensation purposes.

Addition of certain retarders [illegible] water reducers in the superplasticiz[illegible] concrete was studied [illegible] Ramachandran(28) with respect [illegible] slump loss in super plasticized concr[illegible] as super plasticized concretes have [illegible] observed to show loss in slump. It wa[illegible] found to have been extended, in presen[illegible] of super plasticizer, to different exte[illegible] by the addition of various retarders [illegible] Ca-lignosulphonate, sucrose, Na[illegible] gluconate, citric acid, salicylic acid, Na[illegible] heptonate, Na-boroheptonate [illegible] Sodium gluconate was found ve[illegible] effective. This acts as a dispersant [illegible] cement particles and starts hydratio[illegible] of C_3S. The slump can also [illegible] maintained by additions of a polymer [illegible] super plasticized concrete (29[illegible] Repeated dosage of superplasticizer [illegible] extends slump loss time.

Roberts(30) studied the effect of curing time, temperature and cement on the strength of concrete by making use of four different types of cement and different types of super plasticizers, with and without retarders. The use of super plasticizer was found to permit reduction of elevated temperature curing of type III (ASTM) cement. It was found to be governed by the age on which the required strength was needed to be achieved and the type of cement used. In case of the need for lower curing temperature, a water reducer was recommended to be used and a retarder if higher temperature curing was expected. Hampton (31) suggested ways and means to improve fluidity of concrete at higher temperature of 85-90°F (29-32°C) as it goes down within 30 minutes. Modification of naphthalene sulphonate condensate was made with some retarders and the slump loss was checked for longer periods.

Use In Blended And Other Cements

Use of super plasticizers in blended cements or portland cements incorporating silica fume, blast furnace slag or flyash etc. has been found beneficial for strength development. Bache(32) achieved considerably higher strength, 150 MPa at 100 days in super plasticized (1-4 per cent SP) concrete with silica fume (133 Kg/m^3) and cement (400 kg/m^3). In the case of blast furance slag concrete, upto 65 per cent cement has been replaced by blast furnace slag (33) and it was also found that in this case, 10 per cent less superplasticizer than the reference portland cement concrete was needed for achieving the same consistency. But a change in behaviour was observed in such cases. In case of 25 per cent cement replacement level, the strength of air entrained concrete was more than the corresponding super plasticized air entrained concrete at water cement ratio of 0.38. But at 0.46 and 0.56 w/c levels the strength of the super plasticized air entrained concrete was higher than the corresponding air entrained concrete. This needs further study. Valore et al. (34) have found that superplasticizer's use with flyash cement concrete gives good performance.

Table - 1: Comparison Of Different Super Plasticizers For 1 CUM 1 : 2 : 4 Concrete (Cement Content = 6.4 Bags)

Sl. No.	Superplasticizer	Physical State	Density	Shelf life Yrs.	Recommended Dose by wt. of Cement	Quantity of Superplasticizer Required (kg.)	Cost of Super plasticizer Rs./Kg.	Cost of superplasticizer for 1:2:4 concrete in 1 Cum (Rs.)
1.	SIKAMENT	Liquid	1.20	1	0.6 - 3%	1.7 - 5.1	26.50	43 to 135/-
2.	CONPLAST	-do-	1.10	1	0.3 - 0.6%	1.8 - 3.6	12.00	21 to 42/-
3.	Supa plast	-do-	1.17	1	400 - 600 ml	2.2 - 3.1	29.00	64 to 90/-
4.	FOSROC 337	-do-	1.20	1	500 - 700 ml	2.7 - 4.0	32.00	86 to 128/-
5.	FOSROC 430	-do-	1.20	1	500 - 700 ml	2.7 - 4.0	32.00	86 to 128/-
6.	M_c Plast	-do-	1.08	1	0.15 - 0.3%	0.9 - 1.8	49.00	44 - 86/-
7.	Zentrament	-do-	1.30	1	0.5 - 1.0%	2.5 - 5.0	41.00	102.50 to 205/-
8.	CBRI-SP	-do-	1.17	2 Yrs. Old Samples working alright	0.4 - 0.6% (600 - 900 ml)	3.3 - 5.0	5.10	17 - 25.50

Quon and Malhotra (35) used three types of super plasticizers on high alumina cement concrete for slump, strength and degree of hydration studies. At early ages of 10 hours and 2 days a lowering in strength of the super plasticized concrete was observed. At 180 days the strength of the two concretes was comparable, reaching a value of the order of 80 MPa. The addition of SP to high alumina cement does not affect the rate of hydration but at 180 days it was found to have converted 30 per cent less than without SP.

Use In Aggressive Conditions

Walter Lukas (36) tried to find the chloride penetration in super plasticized concrete and observed that high quality concrete with a low water cement ratio had a considerably smaller chloride content than other concrete of same consistency. Similarly a superplasticized concrete has a smaller tendency to absorb chloride than untreated concretes of the same water cement ratio. Hattori (37) showed that reinforcement in a SNF type super plasticized concrete does not show any significant corrosion in a chloride solution while normal concrete shows high corrosion.

Mailvagnam et.al (38) studied the sulphate resistance of cement flyash or slag mortars with super plasticizer and found that mixes containing 30 per cent replacement of normal portland cement with flyash or slag in presence of super plasticizer are comparable to mixes made from sulphate resisting cement in their capacity to resist the sulphate attack. Similar results were reported to have been obtained by Brooks et. al (8) and Collepardi et. al (27).

Modifications On Site Applications

The addition of super plasticizer may result in flowing concrete, when the required water-cement ratio is not altered, or the high strength concrete when the required water-cement ratio is reduced. Flowing concrete mix design is affected by cement type and content, fines content, aggregate properties, maximum placing slump, dosage of super plasticizer and sequence of addition. An important application of such high workability cohesive concrete by use of super plasticizer is in pumped concrete. Some areas where use of super plasticizer has resulted in converting the impossible into successful implementation of concreting ideas are construction of bank vaults (Standard Chartered Bank at Bishopsgate, U.K.), strengthening of bridges and platforms for London Transport Executive where pumpable concrete was produced by use of super plasticizer (39). Other applications include the construction of floor slabs, roof decks, and concrete bay areas. In the base limit of a water treatment plant, closely placed plastic pipes precluded the use of normal vibratory compaction due to unaccessibility for vibratory machine and possibility of pipe damage, thereby calling for the use of super plasticized concrete. Diaphram walling, casting heavily reinforced structural elements and precast units of complex shapes such as construction of toroid shaped dome units of Ninian Platform in Scotland are some other such situations. High strength in concrete realised by the use of super plasticizer may be advantageous for production of high strength precast columns in high rise buildings, girders and also the concrete for nuclear plants for prestressed concrete pressure vessels(40).

Use Of Super Plasticizers In India

Gokhle and Paranjpe (41) advocated indegenous production of super plasticizer for concrete in view of the established beneficial effects reported in the advanced countries. The use of super plasticizer was also envisaged to cut the total cement demand which in a way would supplement the production. Limited trials have indicated that addition of 0.6 per cent and 1.2 per cent of one super plasticizer is able to reduce the water requirement by 15.4 per cent and 23.6 per cent respectively at same workability and the 28 days compressive strength increases by 35% & 51.7% respectively. Chithranjan(42) on the basis of some laboratory investigations concluded that 0.2 per cent super plasticizer addition is optimum for a M 30 concrete and that results in a saving of 30 per cent cement. Aggarwal (43) during the preliminary investigations on the development of a super plasticizer from CNSL found that the slump, compaction factor and the 28 days compressive strength as well as the 3 and 7 days strength increases with the addition of superplasticizer to concrete.

Scope Of Further Investigations

A perusal of the literature cited above makes it clear that good quality concrete can be produced with a low water cement ratio and least possible cement for required strength so that it has a low slump or workability and requires good compactive efforts to produce a dense concrete. But all these conditions are difficult to achieve simultaneously. With the incorporation of super plasticizer, the workability and ease of placement etc. are improved, the water requirement is lowered and improvement in strength occurs. The reduction of water cement ratio leads to higher strength concrete and also brings down cement consumption.

However, all the super plasticizers do not behave similarly. The loss of workability or slump with time of concrete mixing is more with melamine based than the naphthalene based super plasticizer. The change of condensation also shows a difference in behaviour even with similar family condensates. The number of cations present on the super plasticizer and the molecular weight also influence the effectiveness.

The behaviour of the concrete mixes obtained from different type of cements is found affected to different degrees in the presence of super plasticizer. Flyash or slag based blended cements may make a good subject of study in this regard. Concrete of high flyash contents may be designed to utilise the waste for making up the proper paste content and thus alleviate the polluting material. For designing concrete of different properties, the strength of the cement used plays an important role and added to it the effect of the super plasticizer employed. Therefore, in view of availability of different types of cement in India a thorough study on the designing of concrete with a view to rationalise and update the relationship, as given in NBC 1970(44), on strength or grade of cement with grade of concrete and addition of pozzolanic or inert micrograin filler for optimum paste contents in concrete is called for. Extensive trials will give a guideline for economic mix design of concrete with high strength cement in presence of super plasticizer. Ultra high strength concrete shall also be designed by proper evaluation of shape, size, grade of coarse and fine aggregate.

The alteration of concrete properties have been attributed to the presence of super plasticizer which is supposed to affect the hydration characteristics of cement compounds. The addition of super plasticizer has been found to influence the dispersion of the ce-ment particles but their effect is [illegible] ing with the type of super plasticizer, dosage, mixing method and time [illegible] The rate of hydration of cement is [illegible] affected by similar factors [illegible] well as others like temperature, type of cement, its fineness, water content [illegible] However, all these factors have [illegible] been fully studied with regard to con-crete properties. The presence of super plasticizer has been found to alter [illegible] the $CaO:SiO_2$ ratio in C-S-H phase [illegible] in one case it was reported (45) to be altered from 1.19 to 1.21 with addition of 2 per cent SMF. The efficacy of super plasticizer in presence of other materi-als viz retarders, accelerators etc. [illegible] well as the effects of surface area, par-ticle size distribution, C_3A, C_3S, [illegible] alkali contents etc. of cement should be determined. The use of super plasti-cizer beyond a certain limit may pro-duce undesirable effects which [illegible] evaluation. The change in microstruc-ture and morphology of the hydrate phase in presence of different types of super plasticizers can be studied [illegible] explain the compactness, denseness [illegible] permeability of super plasticized con-crete. Therefore, a comprehensive [illegible] on rate of hydration, change of particle size and dispersion of different types of cement in presence of super plasticizers available at present in the country shall be worthwhile.

Super plasticizers have revolutionised concrete technology [illegible] the past two decades in advanced coun-tries but have yet to pick up in India. Very little information is available [illegible] the country on the use and efficacy of various super plasticizers available [illegible] regard to the properties like [illegible] shrinkage, workability, durability, per-meability, behavour in aggressive envi-ronments, corrosion of reinforcement, bonding of old and new concrete etc.

At present super plasticizers [illegible] manufactured by foreign collaborat[illegible] namely Fosroc (U.K.)., Mc-Bauchemie (Germany), Tamol BASF (Germany) [illegible] being marketed, in the country [illegible] addition to some others based [illegible] lignosulphonate. A preliminary information on some of these is given [illegible] Table 1. Their behaviour in tropical countries like India is not thorough[illegible] evaluated which may be of great help to construction agencies. The type and grade, particularly of the fine aggregate changes from place to place which has a considerable effect on the design method and the properties of mortars and concrete. Therefore, a study of the above aspects vis-a-vis the use of different type of Indian super plasticizers may be of great utility.

Another important field of application may be for ferrocement components where 95 per cent of matrix consisting of cement, aggregates, mixing water etc. has a pronounced effect on the behaviour of the final product(46). A super plasticizer is expected to result in reduction of water, increase in strength, reduction in permeability, impart waterproofing and increased durability and reduced reaction between the matrix and galvanised reinforcement. The use of water reducing admixtures shall permit the use of more sand for same design strength which also results in fewer creep strains and less surface cracking.

Acknowledgement

The matter reported in this paper forms part of the normal research programme of the Institute. It is being published with the permission of the Director, CBRI.

References

1. *Rixom, M.R. and Waddicor, J., 'Role of Lignosulphonates as Superplasticizers'. Amer. Concr. Inst., SP-68, 359, (1981).*
2. *Malhotra, V.M. and Malanka, D., 'Performance of Superplasticizers in Concrete-Laboratory Investigations - Part I'. Intern. Symp. Superplasticizer in Concrete, Ottawa, Canada, Vol. II, 673-770, (1978).*
3. *Kasami, H., Ikada, T. & Yamana, S., 'Workability & Pumpability of Superplasticized Concrete - Experiences in Japan', Proc. Intern. Symp. Superplasticizers in Concrete, Ottawa, Canada, 103-32, (1979).*
4. *Mailvaganam, N.P., 'Slump Loss in Flowing Concerete, Superplasticizer in Concrete', Amer. Concr. Inst. SP-62, 389-403, (1979).*
5. *Perenchio, W.F., Whiting, D.A. & Kantro, D.L., 'Reduction, Slump Loss & Entrained Air Void Systems as Influenced by Superplasticizes. Superplasticizers in Concrete'. Amer. Concr. Instt. SP-62, 137-55, (1979).*
6. *Soshiroda, T., 'Segregation Characteristics of Concrete Containing a High-Range Water Reducing Admixture'. Amer. Conct. Instt., SP-68, 121-38, (1981).*
7. *Kishitani, K., Kasani, H., Iizuka, M., Ikeda, T., Kazama, Y. and Hattori K., 'Engineering Properties of Superplasticized Concrete'. Amer. Concr. Instt., SP-68, 233, (1981).*
8. *Brooke, J.J., Wainwright, P.J. & Neville, A.M., 'Time Dependent Behaviour of High Early Strength Concrete Containing A Superplasticizer". Amer. Concr., Instt., SP-68, 81, (1981).*
9. *Tokuda, J., Shoya, M., Kawakami, M.& Kagaya, M. 'Application of Superplasticizer to Reduce Drying Shrinkage and Thermal Cracking of concrete'. Amer. Concr. Instt., SP-68, 101-120, (1981).*
10. *Sivasundaram, V., Carette, G.G. and Malhotra, V.M. Selected Properties of High Volume Flyash Concrete, Concrete International, 47, (1990).*
11. *Dhir, R.K., Hubbard, F.H., Munday, J.G.L., Jones, M.R., Contribution of PFA to Concrete Workability and Strength Development, Cement and Concrete Journal, Vol. 18, 277-89 (1988).*
12. *Ravina Dan and Mehta, P.K., Properties of Fresh Concrete Containing Large Amounts of Flyash, Cement and Concrete Research, Vol. 16, 227-38, (1986).*
13. *Mehta, P.K., Gjorv, O.E., Properties of Portland Cement Concrete Containing Flyash and Condensed Silica Fume, Cement & Concrete Research, Vol.12, 587-95, (1982).*
14. *Rehsi, S.S., 'Ready mixed Flyash Concrete', Engineers and Planners Journal, Vol.2, No.7, Feb. 1974.*
15. *Gupta, S.C., Mehrotra, V.K. and Jain, S.C., 'Use of Flyash to Produce Strong and Durable Concrete', National Workshop on Utilization of Flyash, Roorkee, May 19-20, (1988).*
16. *Dransfield, J.M., Concrete, 7-11, Dec., 1984.*
17. *Kristen, E. and Christensen, N.P., 'Experiences in the use of Superplasticizers in Some Special Flyash Concrete'. Amer. Concr. Instt., SP-68, 1-20, (1981).*
18. *Malhotra, V.M., 'Mechanical properties and Durability of Superplasticized Semi-Light Weight Concrete'. Amer. Concr. Instt., SP-68, 283-305, (1981).*
19. *Nagataki Shigeyoshi, Sakai, Etsuro, Tohru, Takechi, 'The Hydrothermal Reaction of Flyash Cement System and Properties of Autoclaved Concrete with Flyash & Superplasticizer - CAJ', p.158, (1981).*
20. *Mukherji, P.K., Loughborough, M.T. and Malhotra, V.M., 'Development of High Strength Concrete Incorporating a Large Percentage of Flyash and Superplasticizers'. CANMET, Div. Report MRP/MSL, 81-124 (OP&J), (1981).*
21. *Stuart, K.D., Anderson, D.A., and Cady, P.D. 'Compressing strength, studies on portland cement mortars containing flyash and superplasticizer, Cement and Concrete Research, Vol.10, 823-832 (1980).*
22. *Aignesberger, A. and Kern, A., 'Use of Melamine Based Superplasticizer as a Water Reducer'. Amer. Concr. Instt., SP-68, 61-80, (1981).*
23. *Pfeiffenberger, Lucas, E. and Ray, Thomas, B., 'Use of a Superplasticizer in the Manufacture of Extra High Strength Block'. Amer. Concr. Instt., SP-58, 21-40, (1981).*
24. *Murata, J., Kawai, T. and Kokubu, K., 'Studies on the Utilisation of Water-Reduced High Strength Concrete for Monorail Piers'. Amer. Concr. Inst., SP-68, 41-68, 41-60, (1981).*
25. *Ramakrishnan, V., Coyle, W.V., Kopak, P.A., Pasko Thomas, J.Jr., 'Performance Characteristics of Steel Fibre Reinforced Superplasticized Concrete'. Amer. Concr. Instt., SP-68, 515-34, (1981).*
26. *Collepardi, M. and Corradi, M., 'Influence of Naphthalene Sulphonated Polymer Based Superplasticizer on the Strength of Lightweight and Ordinary Concrete'. Proc. Intern. Symp. Superplast in Concr. CANMET, Canada, Energy Mines and Resources, Ottawa, May 29-31, 1978, Vol.2, 451-80, (1978).*
27. *Collepardi, M., Corradi, M. & Valente, M., 'Superplasticized Shrinkage Compensating Concrete'. Amer. Concr. Inst., SP-68, 159-72, (1981).*
28. *Ramachandran, V.S., 'Effect of Retarders / Water Reducers on Slump Loss in Superplasticized Concrete'. Amer. Concr. Instt., SP-68, 393-407, (1981).*
29. *Ramachandran, V.S., Beaudin, J.J., Shihua, Z., 'Control of Slump Loss in Superplasticized Concrete'. Material and Structures, Vol.22, No.128, 107-11, March, (1989).*
30. *Roberts, Laurence, R., 'Cure Temperature Reduction by the use of High-Range Water Reducing Admixtures'. Amer. Concr. Instt., SP-68, 337-58, (1981).*
31. *Hampton James, S., 'Extended Workability of Concrete Containing High-Range Water Reducing Admixtures in Hot Weather'. Amer. Concr. Instt., SP-68, 409-22, (1981).*