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[KEYNOTE PAPER]

The World of Chemical Admixtures in Concrete

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ABSTRACT

The main chemical admixtures in concrete have been classified in ten different types including those commonly used as plasticizers, air entraining agents, etc. or miscellaneous admixtures used for special purposes such as corrosion inhibitors, alkali-aggregate reaction expansion reducers, etc.

The most important aspects of the concrete technology such as workability, strength, durability, shrinkage, creep, etc. are examined in view of the possible improvements caused by the use of chemical admixtures.

A critical survey of the future needs in the field of new admixtures that are still in an experience stage has been carried out.

1.0 INTRODUCTION

Admixtures are ingredients other than water, cement, and aggregate added to the concrete batch during its mixing.
Chemical admixtures are generally used in small amounts and most of them are water soluble or emulsified products. According to this definition chemical admixtures are exclusive of fiber reinforcement, polymer addition, expansive agents, and mineral additions such as fly ash, slag and silica fume.

Tables 1 and 2 summarize the main action of chemical admixtures, their main beneficial effects as well as their potential adverse side effects in using them in concrete.
The most important chemical admixtures include plasticizers, superplasticizers, retarders, accelerators, anti-freezing admixtures, air-entraining agents, and other miscellaneous ingredients such as pumping aids, coloring admixtures, alkali-aggregate reaction inhibitors, corrosion inhibitors.

Table 1: Main chemical admixtures: actions, beneficial and side effects.

CHEMICAL ADMIXTURES:	MAIN ACTIONS:	MAIN BENEFICIAL EFFECTS:	POTENTIAL SIDE EFFECTS:
PLASTICIZERS & SUPERPLASTICIZERS	REDUCTION IN W/C RATIO OR SLUMP INCREASE	CONCRETE QUALITY IN SERVICE PLACEMENT OF CONCRETE	SLUMP-LOSS
RETARDERS	RETARDATION OF CEMENT HYDRATION	TRANSPORTATION AND PLACEMENT	REDUCTION IN EARLY STRENGTH
ACCELERATORS	ACCELERATION OF EARLY CEMENT HYDRATION	REDUCTION IN SETTING TIME & EARLY STRENGTH INCREASE	REDUCTION IN ULTIMATE STRENGTH & DURABILITY
ANTIFREEZING ADMIXTURES	DEPRESSION OF FREEZING POINT OF WATER	CONCRETE PLACEMENT IN VERY COLD WEATHER	CORROSION OF EMBEDDED STEEL
AIR-ENTRAINING AGENTS	DEVELOPMENT OF SMALL AIR BUBBLES	CONCRETE FROST RESISTANCE IN SERVICE	REDUCTION IN STRENGTH

Table 2: Miscellaneous admixtures: actions, beneficial and side effects.

MISCELLANEOUS ADMIXTURES:	MAIN ACTIONS:	MAIN BENEFICIAL EFFECTS:	POTENTIAL SIDE EFFECTS:
ALKALI-AGGREGATE REACTION (A.A.R.) INHIBITORS	REDUCTION IN A.A.R. EXPANSION	UTILIZATION OF REACTIVE AGGREGATES	STILL IN EXPERIENCE STAGE
CORROSION INHIBITORS	PREVENTION OF STEEL CORROSION	PROTECTION OF REINFORCEMENT	STILL IN EXPERIENCE STAGE
PUMPING AIDS	IMPROVEMENT IN PLASTIC PROPERTIES	PUMPING OF LEAN MIXES	HIGH COST/ PERFORMANCE RATIO
DAMPPROOFING ADMIXTURES	WATER REPELLENT ACTION	REDUCTION IN MOISTURE MIGRATION BY CAPILLARY ACTION	SET RETARDATION AND STRENGTH REDUCTION
COLORING ADMIXTURES	PIGMENTATION OF CEMENT MATRIX	CHANGE OF THE ORDINARY GREYCOLOUR	REDUCTION IN COLOR INTENSITY & BRIGHTNESS BY WEATHERING

There has been a continuos development of chemical admixtures as evidenced by published literature and patents [11, 23, 24, 36] and the relevant activity involves mainly cement scientists and material scientists. The present report is not meant to be an exhaustive survey but not more than a review of the trends in the development of chemical admixtures. It is devoted to concrete technologists, engineers, architects and manufactures or users of concrete.
For brevity sake only the main chemical admixtures (Table 1) will be examined in some detail, whereas few comments will be devoted to the miscellaneous admixtures (Table 2).

2.0 PLASTICIZERS AND SUPERPLASTICIZERS

Plasticizers and superplasticizers are chemical admixtures which can be used either to increase the workability of fresh concrete at a given mix composition or to reduce the amount of mixing water of concrete for a given workability. According to a more appropriate terminology, in the latter mode of use these chemical admixtures should be called water reducers and high-range water reducers respectively.

2.1 PERFORMANCES OF PLASTICIZED AND SUPERPLASTICIZED CONCRETES

When these chemical admixtures are used to reduce the amount of mixing water at a given cement content, they are capable of improving all the properties of hardened concrete, such as strength, durability, watertightness, which have a beneficial effect by the reduction in the water/cement (w/c) ratio (Fig. 1, A).
When these admixtures are used to improve the fresh mix workability, plasticizers and superplasticizers do not modify significantly the hardening characteristics of concrete and they merely are helpful to placing concrete particularly in areas of highly congested steel reinforcements (Fig. 1, B).
There is an other mode to use these admixtures, involving reduction of both water and cement, so that workability and strength of the concrete containing admixtures are similar to those of the control concrete (Fig. 1, C). When used in this way, these admixtures act as cement savers and therefore are capable of reducing the drying shrinkage and creep or the heat of hydration, a property that is useful for concreting in hot climates or massive structures.
The main difference between plasticizers and superplasticizers is in the extent rather than in the type of their performances. The slump increase at a given mix composition is about 150-200 mm for the latter and about 50-70 mm for the former. On the other hand, a superplasticizer is capable of reducing water requirements at a given slump by about 20-30% whereas a plasticizer can reduce water contents by about 5-12% only.
Further reductions in mixing water or higher slump increases can be obtained by using plasticizers at higher dosages (as those normally adopted for superplasticizers) but this may result in adverse effects on setting, air volume, and hardening process of concrete (Fig. 2). Therefore, from a practical point of view the main difference between plasticizers and superplasticizers is in the optimum dosage which is about 0.2-0.4% by weight of cement for plasticizers and 1-2% for superplasticizers. The actual dosage of the active ingredients in both these admixtures is really much lower than the above figures since they are generally available in form of 30-40% aqueous solutions to facilitate an accurate, reliable and automatic dispensing at the batching plant.

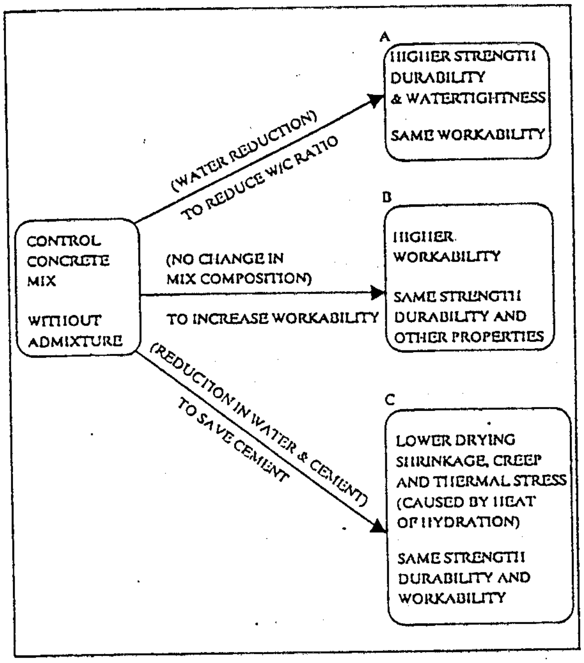

Fig. 1: Schematic diagram illustrating the effect of plasticizers and superplasticizers on the properties of concretes with these admixtures (A, B and C).

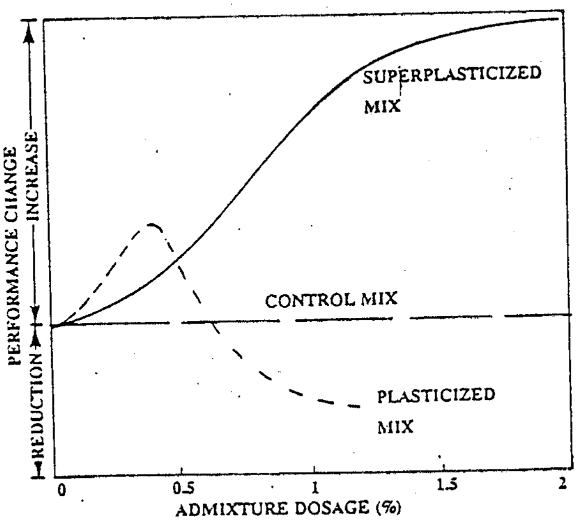

Fig. 2: Schematic diagram of the effect of admixture dosage on the concrete performance in comparison with the control mix.

2.2 COMPOSITION OF PLASTICIZERS AND SUPERPLASTICIZERS

From a compositional point of view plasticizers and superplasticizers may be quite different (Table 3); the main ingredients in the superplasticizers are synthetic water soluble polymers such as sulfonated melamine formaldehyde (SMF) condensate or sulfonated naphtalene formaldehyde (SNF) condensate. Alternative water soluble synthetic polymers have been recently proposed [6, 13, 14, 20, 40] to reduce the slump-loss drawback which can partly or completely cancel the initial technical advantage associated with the use of superplasticizers (low w/c ratio or high slump level). In the absence of these new low slump-loss superplasticizing admixtures - based on carboxylated acrylic ester, CAE, [6] or other products of un-known chemical composition [13, 14, 20, 40] - the slump-loss problem has been faced up by using retarding admixtures as secondary ingredients to partly compensate the stiffening process of the fresh concrete before its placement [11]. In some case chloride-free inorganic salts are used as secondary ingredients to compensate the retarding effect associated with heavily dosed superplasticizer systems (2%).
The main ingredients used in the manufacture of plasticizers are organic products and can be divided into four groups. The first one contains salts of lignosulfonic (LS) acid which can also be used as an important ingredient of superplasticizers when available in a modified form (MLS) consisting mainly in a de-sugarized product with reduced retarding effects. The second group contains salts of hydroxycarboxylic acids (HC). The carbohydrates (CH) belong to the third group, whereas the fourth group contains miscellaneous compounds such as glycerol, polyvinil alcohol, etc. [7]. Other secondary ingredients in plasticizers may be accelerating products such as triethanolamine (TEA) or calcium and sodium of inorganic acids, as well as defoaming agents and anti-bacterial and anti-fungal materials to avoid gas development caused by the transformation of the organic main ingredients.

Table 3 Main and secondary ingredients in plasticizing and superplasticizing admixtures.

SUPERPLASTICIZERS		PLASTICIZERS	
main ingredients	secondary ingredients	main ingredients	secondary ingredients
SNF	MLS	LS/MLS	TEA
SMF	retarders	HC	inorg. salts
CAE	inorg. salts	CH	defoam. agents
Others	TEA	others	anti-bacterial

2.3 FUTURE NEEDS FOR PLASTICIZERS AND SUPERPLASTICIZERS

Since the w/c ratio is the most important parameter affecting the main properties of the concrete in service (strength, durability, etc.) more effective chemical admixtures, which are capable to reduce the w/c without sacrificing the mix workability, will be needed in the future in constructions where concrete with high performances characteristics will be required. From this point of view plasticizers are expected to be progressively replaced by superplasticizers and new synthetic polymers will be tested to attain to:

- cheaper admixtures
- improved slump-loss performance
- increased water reduction capability.

Special and high performance concretes will be required to attain t(

- high compressive strength (30-60 MPa) or ultra high strengt (70-120 MPa)
- high durability against aggressive environments such as in of shore structures, ocean sea floor tunnels, etc.
- special characteristics for repairs or utilization of waste matc rials and solidification of hazardous materials in cement mixe:

3.0 RETARDERS

Admixtures which lengthen setting time and workability time ar known as set retarders or retarding admixtures. Retarders are parti cularly useful for concreting in hot weather where the alternative te chnique to face up to this problem (ice addition to decrease th concrete temperature) is more expensive and may not be readily avai lable at the work site. Attention should be paid to the overdosage o retarders, unless specifically required, because in such a case the re tarding action can be prolonged to the early hardening process (1-: days) and consequently the demolding of forms should be delayed. Traditional retarders are substantially based on the same raw mate rials devoted to the manufacture of plasticizers with different formu lation to enhance the retarding effect [7].
Research efforts on the development of new retarders are relativel few [3, 16, 29, 30] and have been devoted to the case of "extended" o "super" retarders. Two special applications of these new retarders ca be mentioned:

- to improve construction joints
- to re-use returned concrete.

The latter application is related to increasing environmental concerns and restrictions regulating the disposal of returned fresh concrete as well as of truck wash water which are both considered to be hazardous waste according to the classification of many environment protection agencies [11]. Therefore disposal of plastic concrete and truck wash water is becoming one of the most important problems for the ready-mixed concrete companies. The technique is substantially based on the use of a stabilizer and an activator, where the stabilizer is a special retarder that suspends the cement hydration and the activator is an accelerator that reactivates the process. Depending on the stabilizer dosage, the returned concrete can be kept in a plastic state for hours or days.

4.0 ACCELERATORS

Accelerating admixtures are chemicals which can increase the rate of early cement hydration and consequently to reduce the setting time or to increase the early strength development at normal or low temperatures. This enables reduction in the curing and protection periods required to achieve designed strengths in concrete [25].
Table 4 summarizes the main classes of accelerators in different applications and the adverse side effects.

Table 4 Schematic classification of accelerating admixtures.

APPLICATION	TYPE OF ACCELERATOR	ADVERSE SIDE EFFECTS
portland cement set & hardening acceleration	- chloride based admixtures - chloride free admixtures	- steel corrosion - high cost/ performance ratio
portland cement quick setting	- shotcrete admixtures	- A.A.R. expansion - hazards & safety measures - very low ultimate strength
slag activation	- slag activators	- A.A.R. expansion - salts efflorescence

Calcium chloride has been used as accelerator for a long period at least since the year 1873 [25]. It is very cheap and effective as accelerating admixture. However, since the presence of chloride ions in concrete can promote the potential corrosion of the steel reinforcement, an alternative to calcium chloride is one of the most important targets for many researchers in the area of chemical admixtures. Many soluble salts such as thiocyanates, thiosulfates, nitrites, nitrates, aluminates, etc. or organic compounds such as triethanolamine or formates have been tried as ingredients for new admixtures which act as accelerators and do not promote corrosion of steel [4, 18, 27, 32]. However no new admixture is as cheap and performs as well as calcium chloride as accelerator of cement hydration.
Special accelerating admixtures can be considered chemicals which activate the hydration of slag used as hydraulic cement in the absence of portland clinker. Activating admixtures for slags [2, 5, 15, 33, 34] have been proposed which are based on caustic alkalis, alkali silicate and alkali non-silicate salts. Although they are very effective in activating slags, these chemicals can cause some problems such as efflorescence effects, increase in alkali-aggregate expansion, etc. and more research work is needed to solve these problems.
Another special class of accelerators could include shotcrete admixtures that are powerful accelerators of early cement hydration, although these chemical products are not used in regular concrete but only in wet or dry shotcrete process [19].
Shotcrete admixtures require the following main specifications:

- quick setting (within 3 min initial set and 12 min final set);
- rapid compressive strength development (4-8 MPa in less than half an hour).

Since most of the shotcrete admixtures are substantially based on alkali silicate, aluminate, hydroxide or carbonate, used at very high dosages such as 2-6%, the risk of alkali-aggregate expansion in the shotcrete itself, as well as in the regular concrete structure in contact with the shotcrete layer, should be carefully taken into consideration. Therefore, experimental research to find new alkali free shotcrete admixtures is needed in the future even to remove other adverse side effects such as the serious hazards to exposed skin and eyes for the personal equipment and the reduction in the ultimate strength. The latter side effect is present to a negligible extent in ordinary accelerating admixtures and becomes much more remarkable in shotcrete admixtures causing a 28-day strength reduction up to 30% in comparison with the non accelerated mix.

5.0 ANTIFREEZING ADMIXTURES

Antifreezing admixtures are sometimes considered as a special class belonging to the general category of accelerating admixtures. However, the most specific action is to depress the freezing point of water in concrete at temperature as low as -30°C [26]. Most of the accelerating admixtures including those based on calcium chloride at a normal dosage of 2% are capable to depress the freezing point by about 1.5°C which is negligible for many practical purposes [11].
Antifreezing admixtures, which are not popularly used in North America [11], but are widely used in North Europe and in particular in Russia [26], are substantially based on multicomponent systems including inorganic salts such as sodium or calcium nitrite, sodium or calcium chloride, etc., or organic compounds such as alcohols and carbamide [11]. By using these admixtures at dosages as high as 8%, compressive strength of 5 MPa at 1 day and 25 MPa at 28 days can be obtained at curing temperatures as low as -15°C [17].

6.0 AIR ENTRAINING AGENTS

Air entraining agents are admixtures which are capable to form air bubbles dispersed throughout the cement matrix that binds the aggregate. A given value in the air volume (4-6%) and a proper spacing factor (100-200 μm) are required to produce an adequate air bubble system to protect concrete from disruptive stresses caused by ice formation [12]. However, Whiting and Stark [39] have listed 23 factors that affect air entrainment and therefore frost resistance of concrete. Variabilities in sand grading, cement composition, fly ash, temperature, etc. make difficult to adjust the proper air volume to the required value depending on the maximum size of coarse aggregate. New air entraining agents have been developed which are claimed to be superior over the usual vinsol resin based products in terms of evenly spaced air bubbles or more stable air volume [38].
A very interesting and promising new method to produce frost resistant concrete is based on the use of hallow plastic microspheres with size in the range of 10-50 μm [31, 35, 37]. The microspheres can be deformed and partly destroyed by disruptive hydraulic pressure caused by ice formation. However, the original voids into the hollow plastic microspheres are still able to provide empty escape spaces for the excess water where freezing occurs. This method appears to be more reliable than that based on the air entrainment, because the dosage of plastic microspheres is much more accurate than the formation of air bubbles. However, there are some difficulties in controlling the volume of microspheres dispersed in the cement matrix of the placed concrete since the usual pressure method of measuring air volume is not suitable.
The main limit in the use of plastic microspheres appears to be the high cost in comparison with that related to air entrainment.

7.0 MISCELLANEOUS ADMIXTURES

Miscellaneous admixtures include a group of chemical products that are used for special cement mixes and they are not utilized as commonly as the main admixtures examined in the previous sections [19]. A non exhaustive list of these admixtures is shown in Table 2 and includes alkali-aggregate reaction reducers, corrosion inhibitors, pumping aids, dampproofing admixtures,coloring admixtures.

7.1 ALKALI-AGGREGATE REACTION INHIBITORS

The alkali-aggregate reaction (AAR) inhibitors are chemical admixtures which should be capable of reducing the expansion of concrete caused by AAR. The most known method of mitigating the effects of AAR is to incorporate pozzolans or slag and/or to reduce the alkali content in the mix. However, a reliable method of utilizing reactive aggregates has not yet definitely found and the problem is expected to become more important in the future because of the shortage in sound aggregates all over the world.

Therefore, the possibility of using chemical admixtures to reduce the expansion caused by AAR has been taken into consideration in the early '50s, and recently there has been a resurgence of interest in the development of chemicals to inhibit the expansion caused by AAR [11].

The chemicals that have been proposed to inhibit the expansion caused by AAR include mainly salts of lithium (about 1%) and barium (about 2-7%) besides other organic and inorganic compounds [19]. However, these chemicals are either very costly (lithium salts) or inconsistent for their performances and may cause adverse side effects such as strength loss, etc. [19].

Contradictory explanations on the mechanism have been suggested for lithium carbonate as AAR inhibitor: lithium silicates would be produced in form of either soluble silicates on the surface of reactive aggregates without causing swelling [19] or insoluble lithium silicates that are not imbibed by water and therefore reducing swelling [28]. More recent investigations [21] do not confirm the acceptable performances of lithium salts in reducing the AAR expansion and would indicate that other chemicals such as sodium silicofluoride or silane are more effective as AAR inhibitors.

Because of the above limited laboratory data, that are even contradictory each other, more research is required to find effective, reliable and cheaper chemicals for this type of admixtures in view of the growing interest in utilizing even aggregates which are potentially alkali-reactive.

7.2 CORROSION INHIBITORS

Corrosion inhibitors are chemical admixtures which should decrease or prevent the reaction of the reinforcement with the environment and in particular with the chloride salts penetrating through the concrete cover and/or the CO_2 of the air.

The most important chemicals proposed for corrosion-inhibitors [19] are:

- calcium and sodium nitrate, sodium benzoate and sodium chromate acting as anodic inhibitors;
- sodium or ammonium hydroxides and sodium carbonate used as cathodic inhibitors by increasing the pH and reducing the solubility of the ferrous ion;
- organic compounds (e.g. aminobenzenethiol) containing molecules in which electron density distribution causes the inhibitors to be attracted to both anodic and cathodic sites.

Calcium nitrite is perhaps the most popular corrosion inhibitor available on the market and has been proposed to inhibit steel corrosion promoted by chloride [19] as well as by carbonation [1].

A list of mixed compounds systems have been proposed as good potential inhibitors for use in reinforced concrete structures [11].

It is well known that corrosion of steel is promoted by carbonation and specially by the presence of chloride. The most important factor protecting steel from corrosion is the watertightness of concrete cover and its depth. Therefore, in reinforced concrete structures with adequate cover thickness and low w/c ratio, the steel corrosion enhanced by chloride is not a real problem. Collepardi et al. have shown that the use of superplasticizer to reduce the w/c ratio [9] and specially superplasticizer combined with fly ash or silica fume [8] are capable to reduce the permeability of the cement matrix and therefore to reduce the carbon dioxide and chloride penetration through the cover, and then to protect the reinforcement from the subsequent corrosion (Fig. 3-6).

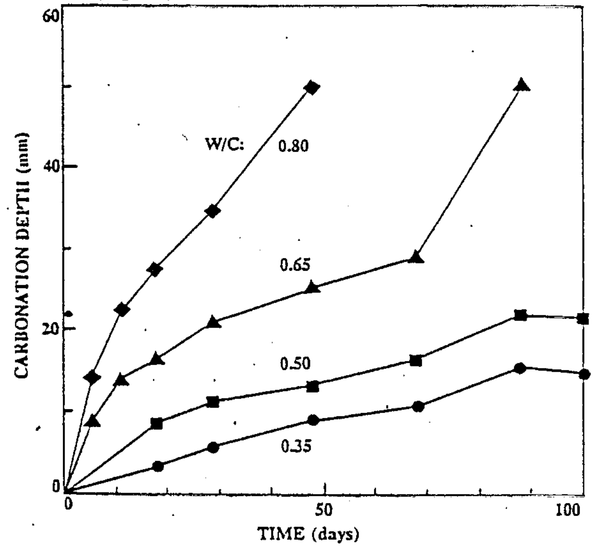

Fig. 3: Influence of the water/cement ratio on the carbonation depth of Portland cement concretes in a 30% carbon dioxide enriched atmosphere [9].

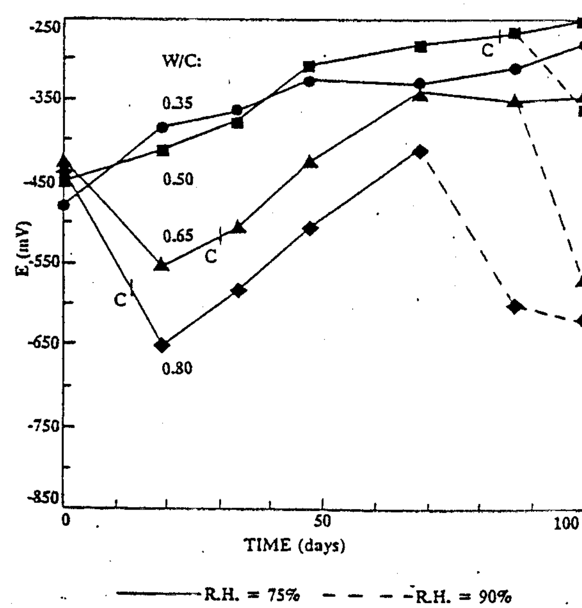

Fig. 4: Influence of the water/cement ratio on the electrochemical potential (E) of the rebars in Portland cement concretes with 20 mm concrete cover in a 30% carbon dioxide enriched atmosphere. C indicates that the cover is completely carbonated [9].

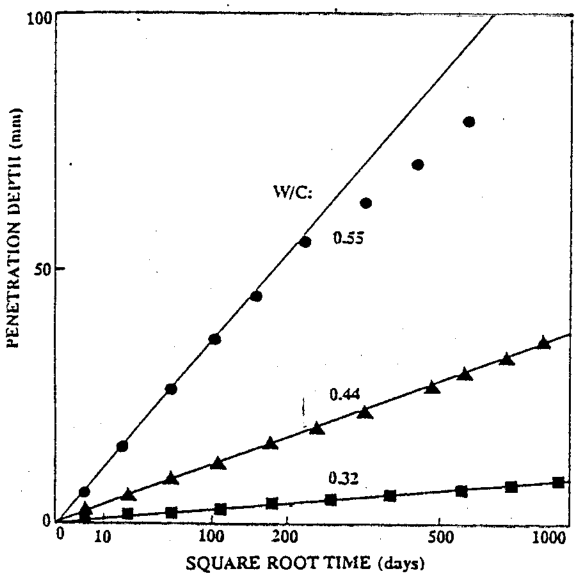

Fig. 5 Chloride penetration in concrete with different w/c ratios [8].

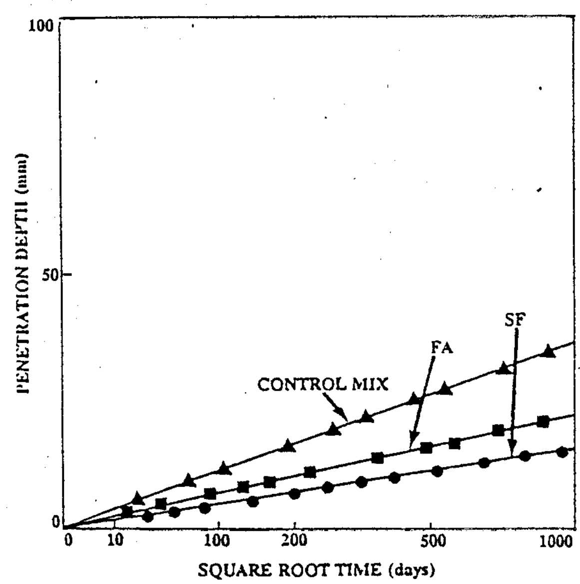

Fig.6 Effect of fly ash (FA) or silica fume (SF) addition on chloride penetration in concrete with a w/c of 0.44 [8].

On the other hand, in reinforced concrete structures with cracked cover, chloride penetration can occur by diffusion and/or capillary action independently of the permeability of the cement matrix. Consequently, corrosion inhibitors should act just in these circumstances even because concrete ductility is very poor and therefore the cracking cover caused by drying shrinkage or dynamic loads cannot be excluded.

Unfortunately many corrosion inhibitors would act effectively in uncracked reinforced concrete structures, whereas are not effective or would even aggravate very seriously the corrosion of steel in the presence of cracked cover [10].

In view of these contradictory results more research efforts should be devoted in the coming years to the development of reliable and effective chemicals as corrosion inhibitors, particularly for reinforced concrete structures exposed to the potential risk of cracking. Alternatively, ductile, durable and impervious coating on the concrete surface should be used to protect the cover from chloride penetration and reinforcement from corrosion.

7.3 PUMPING AIDS

Pumping aids are special admixtures that are generally used to pump lean mixes marginally pumpable, whereas in cement rich concrete mixes pumpability may be improved by using other common admixtures such as plasticizers, superplasticizers or air entraining agents. Pumping aids generally act as improvers of plastic properties. There is a long list of chemicals devoted to the manufacture of pumping aids that includes water soluble organic polymers such as polyethylene oxide, starch, ether, etc. or inorganic materials in form of fine particles such as bentonite, kaolin, etc. [19].

On the other hand, pumpability of lean concrete mixes can be improved by increasing the cement content or even better by adding fine pozzolanic materials such as fly ash. Therefore, the main problem of pumping aids is to reduce the cost in comparison with that related to the increase in the cement content or the amount of fly ash addition. The wide availability and the low cost of the latter material has substantially reduced the use of pumping aids even because the addition of fly ash to a lean mix does not change the heat development when the concrete is devoted to massive concrete structure (e.g. foundations).

7.4 DAMPPROOFING ADMIXTURES

Water can penetrate concrete under conditions of pressure through pores continuously interconnected or by absorption through migration of moisture by capillary action.

Admixtures that reduce water penetration under pressure are called waterproofing admixtures and act by reducing the permeability of the cement matrix, whereas admixtures that reduce moisture migration by imparting hydrophobic character to the hardened concrete are called dampproofing admixtures [19]. Waterproofing admixtures are substantially based on combined systems of water reducers and/or finely divided solids, such as fly ash or silica fume, which act as inert pore filling materials. Therefore, only dampproofing admixtures will be shortly examined in the present report.

Dampproofing admixtures are in general ineffective in reducing water penetration under a positive hydrostatic head and therefore they should not be used to produce watertight concrete in hydraulic works. They are generally devoted to special concrete works (e.g. foundation) where for some reason high w/c ratio is adopted and capillary absorption of water from the moist surrounding ground should be avoided. However, in such a case plasticizers or superplasticizers, used to reduce the w/c ratio could act as waterproofing admixtures

more effectively and perhaps more economically than the dampproofing admixtures.
Moreover, dampproofing admixtures can prolong setting times and reduce strength particularly when undesiderable air entrainment is induced by these admixtures.

7.5 COLORING ADMIXTURES

The normal grey color of cement based structures can be changed by applying colored coatings on the surface after the concrete has hardened or introducing integral coloring admixtures into the mass while the concrete is still plastic. Due to the cost of integral coloring admixtures the color is generally changed by applying colored coatings on the hardened concrete surface. However, for some special purpose integrally colored concrete is sometimes required.
Coloring admixtures basically contain natural and/or synthetic pigments which are inorganic (iron and chromium oxides) and sometimes organic compounds [19].
The main problems related to the use of coloring admixtures [19] are: uniformity in color shade and brilliance, resistance to weathering agents such as water, light and heat, and resistance to aggressive chemical environments.
The ultimate result in coloring concrete structures depends on many parameters including type of coloring admixtures such as natural or synthetic pigments, particle size, addition procedure for the concrete ingredients, concrete composition, etc.

8.0 CONCLUSIONS

In coming years there will be an increasing demand for the development of concrete constructions whith special performances that will be able to resist the aggressive actions of hostile environments, such as off-shore structures, sewage pipes, underwater concreting ocean sea floor tunnels, structures exposed to chemical and radiactive materials. For the utilization of waste materials and solidifications of hazardous by-products, special concrete mixes will be needed [11]. Moreover, special cement mixes will be required for repairs of infrastructural deteriorated concrete works such as dams, highways, bridge decks, etc.
For all such applications superplasticizers alone or in combination with mineral additions, such as fly ash or silica fume, will play a very important role. More effective superplasticizing admixtures with higher capability in reducing w/c ratio as well as slump loss will be required to produce durable and high strength concrete.
More reliable air void systems to produce frost resistant concrete are also needed, and plastic microspheres instead of air entraining agents could be used provided that more economical materials will be available.
New chemical admixtures, including akali-aggregate expansion reducers and corrosion inhibitors, will be required to produce more durable concrete structures, whereas admixtures for re-use of returned concrete will be required to face up to the environmental concerns and restrictions for the disposal of returned plastic concrete and truck wash water.

9.0 REFERENCES

[1] Alonso C. - Acha M. - Andrade C.
"Inhibiting Effect of Nitrites on the Corrosion of Rebars Embedded in Carbonated Concrete", RILEM Symposium "Admixtures for Concrete. Improvement of Properties", Chapman & Hall, London, pg. 219-228, 1990.

[2] Andersson H. - Gram H.E. - Malolepszy J. - Deja J.
"Alkali-Activated Slag" Swedish Cem. and Concr. Res. Inst. No. 1-88, 1988, pg. 104.

[3] Anonymous.
"Chemical System Puts Hydration for Hours or Even Days", Concrete Construction., Vol. 33, 1988, pg. 24.

[4] Brook J.W. - Beckley R.A. - Farzam H.
"A Non-Chloride Accelerating Admixture for Class CF Fly Ash", Concrete International, Vol. 12, 1990, pg. 51-54.

[5] Byfors K. - Klingstedt G. - Lehtonen H.P. - Romben L.
"Durability of Concrete Made With Alkali-Activated Slag", 3rd Intl. Conf. on "Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete", Amer. Conc. Inst. SP-114, 1989, pg. 1429-1444 (Editor: V.M. Malhotra).

[6] Collepardi M. - Coppola L. - Cerulli T. - Ferrari G. - Pistolesi C. Zaffaroni P. - Quek F.
"Zero Slump-loss Superplasticized Concrete", paper for the Congress "Our World in Concrete and Structures", Singapore, August, 1993.

[7] Collepardi M.
"Water reducers/Retarders", Chapter III, pg. 116-210, in reference [24].

[8] Collepardi M. -Biagini S.
"Effect of water/cement ratio, pozzolanic additions and curing time on chloride penetration into concrete", Proc. of "IX European Ready Mixed Concrete Organization Congress", ERMCO '89, Stavanger, Norway, pg. 606-615.

[9] Collepardi M. - Fratesi R. - Moriconi G. - Biagini S.
"The use of superplasticizers as steel corrosion reducers in reinforced concrete", RILEM Symposium on " Admixtures for Concrete. Improvement of Properties", Chapman & Hall, London, pg. 269-278, 1990.

[10] Collepardi M. - Fratesi R. - Moriconi S. - Coppola L. - Corradetti C.
"Use of nitrite salt as corrosion inhibitor admixture in reinforced concrete structures immersed in sea-water", RILEM Smposium "Admixtures for Concrete. Improvement of Properties", Chapman & Hall, London, pg. 279-288,1990

[11] Collepardi M. - Ramachandran V.S.
"Effect of admixtures", Proceedings of the 9th International Congress on the Chemistry of Cement, New Dehly India, Vol. 1, Theme III D, pg. 529-570, 1992.

[12] Dolch W.L.
"Air entraining agents", Chapter V, pg. 269-302, in reference [24].

[13] Fujiu A. - Tanaka H. - Iizuka.
"Slump Control by Reactive Polymer Dispersant", Rev. 39th General Meeting, Cement Association, pg. 72-73, Japan, 1985.

[14] Fukuda M. - Mizunuma T. - Izumi T. - Iizuka M. - Hisaka M.M.
"Slump Control and Properties of Concrete with a New Superplasticizer. I: Laboratory studies and test methods", Proceedings of the In-

tern. RILEM Symposium on "Admixtures for Concrete. Improvement of Properties", Chapman & Hall, London, pg. 10-19, 1990.

[15] Gjorv O.E.
"Alkali Acivation of Norwegian Blast Furtnace Slag", 3rd Intl. Conf. on "Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete", Amer. Conc. Inst. SP-114, 1989, pg. 1501-1517, (Editor: V.M. Malhotra).

[16] Ho. K. - Takeuchi T.
"Application of the Super Retarders", Sement KonKurito, Vol. 471, 1986, pg. 31-37.

[17] Kivekas L. - Leivo M.
"Research and Use of Antifreeze Admixtures in Finland", III Intern. RILEM Symposium on Winter Concreting, Espoo, Finland, 1985, pg. 208-222.

[18] Kuroda T. - Goto T. - Koboyashi. S.
"Chloride-Free and Alkali Metal-Free Type Accelerator", Concrete Association Japan Rev., 1986, pg.194-197.

[19] Mailgavanam N.P.
"Miscellaneous admixtures", Chapter IX, pg. 480-557, in reference [24].

[20] Mitsui K. - Kasami H. - Yoshiota Y. - Kinoshita M.
"Properties of High Strength Concrete With Silica Fume Using High Range Water Reducer of Slump Retaining Type" in " "Superplasticizers and Other Admixtures", Amer. Concr. Inst. SP-119, pg. 79-97, 1989.

[21] Ohama M. - Demura K. - Kakegawa M.
"Inhibiting Alkali-Aggregate Reaction With Chemical Admixture", 8th International Conference on "Alkali-Aggregate, Reaction", Kyoto, Japan, 1989, pg. 253-258.

[22] Popovics S.
"Strength-Increasing Effects of a Chloride-Free Accelerator", Am. Concr. Inst., SP-102, 1987, pg. 79-106.

[23] Proceedings of the Intern. RILEM Symp. on "Admixtures for Concrete, Improvement of Properties", Barcelona 1990, Ed. E. Vasquez, Chapman and Hall, London, 1990.

[24] Ramachandran V.S.
"Concrete Admixtures Handbook. Properties, Science, and Technology", Noyes Publications, Park Ridge, New Jersey, USA, 1984.

[25] Ramachandran V.S.
"Accelerators", Chapter II, pg. 54-115, in reference [24].

[26] Ratinov V.B. - Rozenberg T.I.
"Antifreezing Admixtures", Chapter VIII, pg. 430-479, in reference [24].

[27] Rear K. - Chin D.
"Non-Chloride Accelerating Admixtures for Early Compressive Strength", Concrete International, Vol. 12, 1990, pg. 55-58.

[28] Sakaguci Y. - Takakura M. - Kitagawa A. - Hori T. - Tomosawa F. - Abe M.
"The Inhibiting Effect of Lithium Compounds on Alkali-Silica Reaction", 8th International Conference on "Alkali-Aggregate Reaction", Kyoto, Japan, 1989, pg. 229-234.

[29] Shiiba H.
"Super Retarders for Concrete", Konkurito Kogaku, Vol. 26, 1988, pg. 50-54.

[30] Shiiba H. - Honda S.
"Effect of Super Retarding Admixtures on Concrete Construction Joints Under Various Conditions", Fukuoda Daigaku Kogaku Shuho, Vol. 39, 1987, pg. 93-102.

[31] Sommer H.
"A New Method of Making Concrete Resistant to Frost and De-Icing Salt", Betonwerk Fertigteit-Technick, Vol. 9, pg. 476-484, 1978.

[32] Tachihata S. - Kotani H. - Joc. V.
"The Effect of Triethanolamine on the Hydration Mechanism and Strength Development of Slag Cement", Silic. Ind., Vol. 49, 1984, pg. 107-112.

[33] Talling B.
"Effect of Curing Conditions on Alkali-Activated Slags", 3rd Intl. Conf. on "Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete", Amer. Conc. Inst. SP-114, 1989, pg. 1485-1500 (Editor: V. M. Malhotra).

[34] Talling B. - Brandstetr J.
"Present State and Future of Alkali-Activated Slag Concretes, 3rd Intl. Conf. on "Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete", Amer. Conc. Inst. SP-114, 1989, pg. 1519-1545 (Editor: V. M. Malhotra).

[35] Tavano S.
"Reinforced Concrete Resistant to Frost and De-icing Salt: New Developments", L'Edilizia, Vol. 10, pg. 737-740, 1988.

[36] Third CANMET/ACI Intern. Conf. on "Superplasticizers and other chemical admixtures in concrete", Ottawa 1989, Ed. V.M. Malhotra, ACI, Detroit, Michigan, 1989.

[37] Vanhanen A.
"Air-Entraining Agents For Frost-Resistance of Concrete", Lab. Report No. 73, Tech.Res. Centre, pg. 73, Finland, 1980.

[38] Weigel T.A. - Mohsen J.P. - Hagerty D.J.
"A Study of Some Aspects of Micro Air Entraining Admixtures in Fly Ash Concrete", Proceedings of the Intern. RILEM Symposium on "Admixtures for Concrete. Improvement of Properties". pg. 578-582, Barcelona, Spain, 1990.

[39] Whiting D. - Stark D.
"Control of Air Content in Concrete", NCHRP Report No. 258, Trans.Res.Board, Washington, pg. 84, May 1983.

[40] Yamakawa C. - Kishtiani K. - Fukushi I. - Kuroha K.
"Slump Control and Properties of Concrete with a New Superplasticizer. II: High strength in situ concrete work at Hicariga-Oka Housing Project", RILEM Symposium on "Admixtures for Concrete: Improvement of Properties", Chapman & Hall, London, pg. 94-105, 1990.