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Admixtures for Recycling of Waste Concrete

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Abstract

Recent developments in admixture technology have made significant progress to control the hydration of cement. This control has enabled concrete producers and users to stop cement hydration for a desired period and be able to restart it at any time, allowing the concrete to set normally, without sacrificing any of the properties of the hardened material. These types of admixtures, defined as extended-set control admixtures,[1] *not only have a significant influence on the production, transportation, and placement of concrete, but have also had a positive impact on the environment. With this technology, in fact, it is possible to eliminate or greatly reduce the amount of waste in the production and use of concrete. The control of the hydration is currently achieved by the use of two admixtures, one defined as 'Stabilizer' is capable of stopping or stabilizing the hydration of cement, when it is mixed in the concrete, while the second, named 'Activator', is used to restart or activate the hydration. The extended set-control admixtures were originally developed for overnight and weekend stabilization of returned plastic concrete, for the long-haul stabilization of concrete that has to be placed at long distances from the batching plant and for overnight or weekend stabilization of concrete wash water from truck drums. The use of this system for the above mentioned applications allows a sensible reduction, or even an elimination, of the waste in the production and use of concrete, and as a consequence a cost reduction for the producers and users of concrete. Other potential uses include in Roller Compacted Concrete (RCC) applications and in shotcrete. This paper deals with an overview of the chemistry and mechanisms of action of these admixtures, their main practical uses, the effects of the use of extended set-control admixtures on the properties and durability of concrete in comparison with reference concrete, and with an overview of some other applications where this system has been successfully used.*

Keywords: concrete, admixtures for concrete, waste concrete, wash water, extended-set control admixtures, retarding admixtures, Roller Compacted Concrete, shotcrete.

WASTE CONCRETE AND MIXER WASH WATER

Every year a substantial amount of the ready-mixed concrete produced is returned for disposal for many reasons, such as excessive slump loss during transport, or when more concrete is ordered than can be used at site. Also a huge amount of water, approximately 1500 l per truck, is used every day to wash out truck drums, with about 300 kg of mortar remaining inside each truck mixer. Disposal of wash water is often accomplished by discharging it into a wash water pit.[2]

Both waste fresh concrete and mixer wash water are classified as hazardous waste in the USA (Environmental Protection Agency) as well as in most European countries. As a consequence the disposal of these materials is highly regulated by the different environmental legislations. The availability of landfills authorised for disposal of waste fresh concrete and wash water will be significantly reduced in the future and, as a result, the costs to be borne by the concrete producers for disposal will increase.

TRADITIONAL METHODS OF DISPOSAL

Traditional methods of disposal include dumping at the jobsite or in a landfill, discharging into a concrete reclaimer or recycling unit, producing highway barriers or other minor precast elements, or constructing pads or bulkheads at the ready mixed concrete plant. Returned concrete may be discharged directly on the ground. Before dumping it, the driver can add water, sand, or air entraining admixture to make the hardened material easier to break up. After it hardens, loaders are used to break up the concrete before it is hauled to a landfill or stockpiled for later crushing and recycling. The costs of this disposal method include truck driver and loader operator time, fuel and truck mileage in getting to the discharge site and back, and costs for crushing and hauling the hardened concrete to a landfill for storage site. The final cost of this operation has to include also the dumping fee.[3]

A series of interconnected washout pits or basins can be used to allow progressive settlement of cement solids and other fines. Most of the coarse particles settle in the primary basin. Excess water flows over a weir into a second basin, where finer particles settle, and then into a third basin that contains relatively clear water. For ready mixed concrete plants with many trucks a fourth basin may be needed as well.

The clarified water can be re-used for washing out trucks or as mixing water in new batches. If the washout pits are not at the batch plant, this option also incurs driver, fuel, and mileage costs. Even if they are at the batch plant, the expense of periodically disposing of material that has to be shovelled out of the pits must be considered. If all of the clarified water cannot be re-used, it must be treated with acid or carbon dioxide to reduce the pH prior to disposal.

Making large concrete blocks, landscaping blocks or other shapes provides a partial payback for some producers who use the blocks around their plant or sell them. Forming and labour costs have to be considered when evaluating the economics of this solution. If the market for these products is small, the producer may soon own a large unwanted block inventory that takes up space without generating revenue.

THE EXTENDED SET-CONTROL ADMIXTURES: AN ALTERNATIVE TO THE DISPOSAL

A cost effective alternative to the traditional methods of disposing of the waste fresh concrete and of the mixer wash water consists in the use of extended set control admixtures. The Delvo System developed in the last few years is a two part chemical system which can reduce ready mix concrete waste to a minimum. In the technique concrete is kept fresh for longer periods making possible its storage and later use. The first component of the system or 'Stabilizer' is composed of carboxylic acids and phosphorus containing organic acids and salts, and is capable of coating cement particles to suspend hydration and interacts with hydration products that are in solution. Depending on the dosage, the concrete mix can be maintained in a deactivated state for hours or days (maximum 3 days).

The second part of this system, the 'Activator', is then added to remove the coating, allowing hydration to proceed. The Activator can be defined as a hydration accelerator. Both the stabilizer and the activator are two chloride free admixtures.

MECHANISM OF ACTION OF THE STABILIZER

It is well known that the cement hydration can be easily delayed with the use of retarders. The retarders generally act in a solution with the mixing water, and they influence the hydration products by superficial coating of the cement grains. Their action influences more the hydration of C_3S and C_2S rather than the hydration of C_3A, and as a result the retarders are able to affect more the early strength development by delaying it, rather than modifying the initial rheology of fresh concrete.[4]

Using calorimetric measurements it is easy to follow the hydration process and to monitor the effects of retarders. Figure 1 shows the typical curve of heat evolution of a cementitious mix with a retarder in comparison with a reference. As can be seen, the retarder does not modify

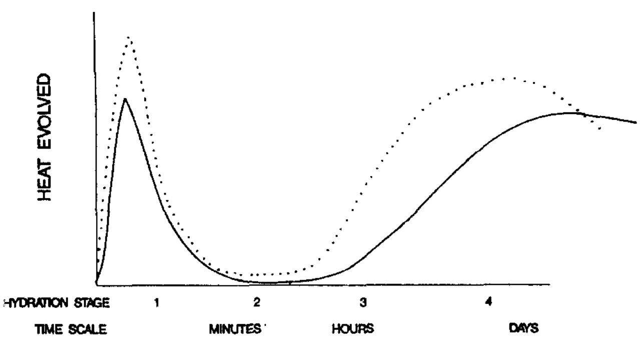

Fig. 1. Scheme of the hydration development of a retarded system in comparison with a reference mix.

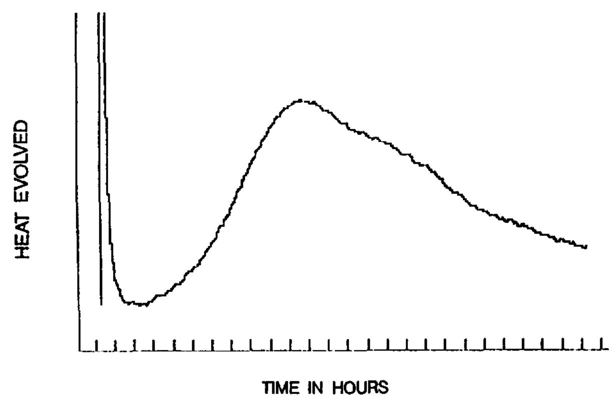

Fig. 2. Heat evolution diagram of a standard cementitious mix.

the time of hydration of C_3A (first peak on the left), while it substantially delays the time of hydration of C_3S and C_2S (second peak on the right).

It is also well known that if the dosage of the retarder is very high, it is possible to have a permanent stoppage of hydration, which cannot be reactivated. In these situations the only remedy is to replace the concrete. Another possibility which can happen with an overdosage of retarders is fast setting, i.e. the mix loses workability rapidly, stiffens and shows behaviour which is similar to that shown by cements in which gypsum is absent or used at a very low dosage.

The mechanism of action of the stabilizer is quite different from that used by conventional retarders. The stabilizer is capable of retarding all clinker minerals and lowering the rate of calcium sulphate mineral solution. Conduction calorimetric analysis and scanning electron microscopic examinations of the surfaces of stabilized and activated alites have shown that the stabilizer inhibits CSH and CH nucleation. Cement hydration is arrested by the admixture which acts on all phases of cement hydration including the C_3A fraction.

The stabilizer is a surface active agent designed to prevent surface nucleation of calcium ion rich hydrates. When nuclei have already formed, the stabilizer retards their growth and alters the external morphology of subsequently formed hydrates. The ability of the stabilizer to stop formation of primary CSH hydrates and its moderate slowing of C_3A suggests that in Portland cement the stabilizer prevents epitactic growth of primary CSH on C_3S, while only slightly slowing C_3A hydrates from precipitating out of the solution.

Figure 2 shows the heat evolution of a reference cementitious mix in which the peaks of hydration of C_3A (first peak on the left) and of C_3S and C_2S are clearly distinguished, while Fig. 3 shows the heat evolution curve of the same mix additioned with the stabilizer. It is evident that the stabilizer reduces the height of the first peak and indefinitely delays the rise of the second peak.

Figure 4 depicts what happens to a stabilized mix when it is activated, the hydration process restarts regularly as if cement had just been mixed with water. A mix can be stabilized right from the beginning of mixing as well as some time after mixing, Fig. 5 shows the heat evolution of a mix stabilized after 5 h from mixing and then reactivated after 25 h. Once the activator is added to the stabilized mix, or when the effect of the stabilizer wears off, the cement spontaneously begins to hydrate, and the concrete normally stiffens and hardens, producing a good quality material.

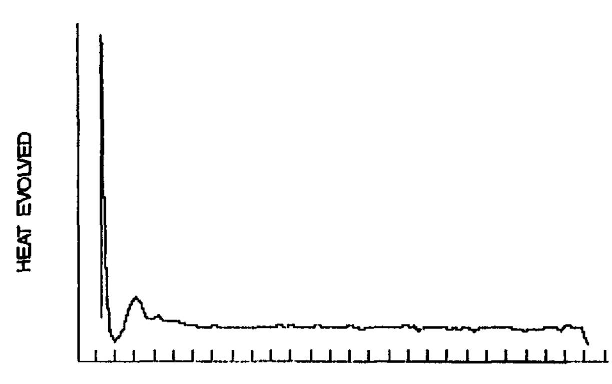

Fig. 3. Evolution diagram of a cementitious mix additioned with the extended-set control admixture.

ADMIXED STABILIZER, ACTIVATED AT 25 HRS.

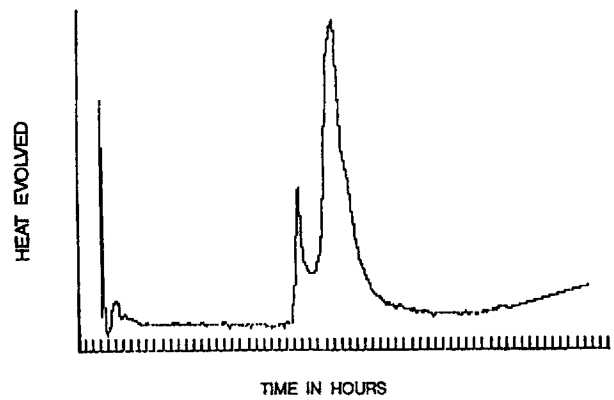

Fig. 4. Evolution diagram of a cementitious mix stabilized and reactivated after 25 h

DOSAGE

The dosages of stabilizer and of activator are dependent on a large number of parameters, like cement type and content, elapsed time from initial batching, the temperature for the returned plastic concrete, the quantity of concrete being treated, and the time for which it has to be stabilized.

The recommended dosage range of stabilizer for same-day, overnight and weekend stabilization of concrete is 0·065 to 8·5 l per 100 kg of cementitious material.

Activation of such stabilized concrete is achieved by using a dosage range of activator from 0 to 10 l per 100 kg of cementitious material. For overnight stabilization of concrete wash water the amount of stabilizer may range from 1 to 2 l per truck, while for weekend stabilization the dosage range of stabilizer may vary between 2 and 3 l per truck.

STABILIZED AT 5 HRS.: ACTIVATED AT 25 HRS

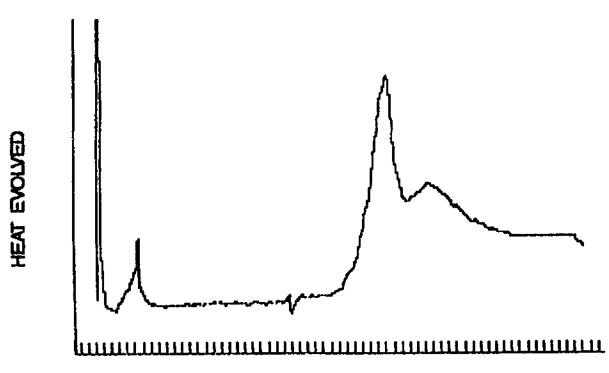

Fig. 5. Evolution diagram of a cementitious mix stabilized after 5 h from mixing and reactivated after 25 h.

Unlike conventional retarders, the stabilizer can be used at high dosages without the attendant adverse effects such as flash set and poor strength development characteristics resulting from the use of normal retarders.

TYPICAL APPLICATIONS FOR THE EXTENDED SET CONTROL ADMIXTURES

The extended set control admixtures were originally developed for two applications: overnight and weekend stabilization of returned plastic concrete. With the addition of the appropriate dosage of stabilizer, returned fresh concrete can be maintained in a plastic state in the truck mixer or in a central holding container for 12 to 18 h in the overnight stabilization application and for approximately 72 h for the weekend stabilization application. The following day or after the weekend the concrete is activated with the activator, and then combined with newly batched concrete and sent to the project site.

Both the overnight and weekend stabilization applications typically require that water along with the stabilizer has to be added to returned fresh concrete. For overnight stabilization the water that should be added should be sufficient to have a concrete with 10–15 cm slump, while for the weekend stabilization the amount of water added has to bring plastic concrete to a slump of 18–24 cm. It is important to add the stabilizer to high slump mixes in order to get a uniform distribution of the admixture. It is imperative that the concrete producer account for this additional mixing water when batching the new concrete which is to be combined with the stabilized concrete. This is done by withholding the same quantity of water or more from the newly batched concrete as was added to stabilized concrete.

Other than the reduction in mixing water, the proportions of the stabilized and newly batched concrete are the same. The ratio of newly batched concrete to stabilized concrete should be approximately 3 to 1 for both applications. Even at this ratio, the activator or accelerating admixture is required to let the combined concrete experience normal times of setting.

The same-day stabilization of returned fresh concrete allows concrete producers to stabilize the concrete either immediately upon return to the plant, so that new concrete may be batched on top of stabilized concrete and immediately used, or to stabilize returned fresh concrete for a short period until the producer is able to locate a site where it may be used.

Long-haul stabilization is used to control the rate of cement hydration for concrete that will be transported for long distances. Not only is the setting time retarded, but concrete stiffening is delayed. Knowing the transport time the concrete producer adds the appropriate dosage of stabilizer at the time concrete is initially batched. During the period of stabilization, the slump will be retained, and no temperature rise will occur. By the time the concrete arrives at the project site, the concrete begins to experience normal setting behaviour, so that finishing and form removal operations may proceed without any delay.

Another very important and well experienced application for this system consists in the overnight or weekend stabilization of wash water from truck drums.

At the end of each day, when an 8 m^3 ready mix truck returns to the plant with no leftover concrete, that truck will contain approximately 350 kg of cement, fine and coarse aggregate adhering to the inside of the truck drum. It is necessary to wash this residue out using approximately 600 to 1500 l of water to thoroughly clean the inside of the truck drum.

Conventional methods for the disposal of concrete wash water include dumping at the jobsite, at a landfill, into a reclaimer/recycler unit, into a concrete wash water pit, or in the ready-mix plant. The removal of hardened material from the wash water can result in expensive labour costs, excessive wear and tear on front-end loaders, and costly hauling charges.[5] The stabilizer can be used with just 100 to 200 l of water to stabilize the wash water in the drum of a truck mixer, the stabilized wash water can then be re-used as mix water in the subsequent manufactured concrete either the next day or after a weekend.

The water content of the freshly manufactured concrete has to be reduced by the amount of water added during the stabilization phase.

The concrete manufactured with the stabilized water may also be re-stabilized if necessary. The stabilization of wash water greatly reduces the amount of water needed to clean the truck drums of the truck mixers, reduces the labour costs, and eliminates concrete wash water disposal.

Another typical application of this system consists in the stabilization of leftover concrete from pump lines in the concrete hopper. The cleaning of concrete from pump lines during and/or after the work day can be time consuming and result in expensive labour costs. The leftover concrete form pump lines can be stabilized in the concrete hopper on a same-day/overnight basis.

The stabilized concrete is then pumped into the ready-mix truck for mixing before re-use.

EXPERIMENTAL PROGRAM

To fully verify the performance and features of the system, and to further develop new applications for this technology, with the declared aim of reducing concrete mixture costs and minimizing the adverse environmental impact associated with the disposal of waste fresh concrete, Master Builders and the US Army Engineer Waterways Experiment Station (WES) entered into a Cooperative Research and Development Agreement.[6]

The first part of the program consisted in evaluating reference concrete mixes manufactured to obtain same-day stabilized, overnight stabilized mixtures, long-haul stabilized mixtures and elevated-temperature mixtures to take into account the fact that today much concrete is placed at temperatures in excess of those maintained in the laboratory. For this reason a short study was conducted to determine the effects of increasing the concrete temperature (+35°C) on low-cement content stabilized mixtures. Four reference mixtures were proportioned and tests were carried out on fresh and hardened concrete. Each of the four mixtures was then evaluated in the laboratory under conditions that simulated same-day, overnight, and long-haul stabilization of fresh concrete to determine how the fresh and hardened properties changed.

Two types of cement and two cement contents (310 and 390 kg/m^3) were used in the concrete mixes to obtain a clear picture of the performances of the stabilized mixes. Each mixture was proportioned to achieve a slump of 10 ± 1 cm and an air content of $6 \pm 1\%$. The mixture proportions of a reference mix are given below.

Proportions of a reference concrete mix used in the experimental work:

Cement brand:	Capitol Cement Type I
Cement content:	390 kg/m^3
Fine aggregate:	656 kg/m^3
Coarse aggregate:	1 140 kg/m^3
Water to cement ratio:	0·42

The properties of concrete investigated were the following: temperature, slump, unit weight and air content of the fresh concrete, and setting time, compressive and flexural strength, static modulus of elasticity, resistance to rapid freezing and thawing, length change, resistance to chloride-ion penetration, and parameters of air–void system. All the tests done on fresh and hardened concrete followed standard procedures of ASTM. The results of the investigation conducted on the use of the stabilizer for same-day, overnight, and long-haul applications indicated the following.

(a) The properties of all fresh mixtures representing the three stabilization applications were comparable to those of the untreated reference mixtures.
(b) Fresh concrete at laboratory temperatures stabilized for same-day, overnight, or long-haul applications had both compressive and flexural strengths 90% or greater than those of untreated reference mixtures (Fig. 6 and Fig. 7). At several of the ages that specimens were tested, the stabilized concrete showed higher values of strength in comparison with the unstabilized reference mixtures.
(c) The resistance of the stabilized mixtures to rapid cycles of freezing and thawing as defined by the durability factor, approached 100% that of the reference mixtures.
(d) The same-day and long-haul stabilized mixtures experienced drying shrinkage

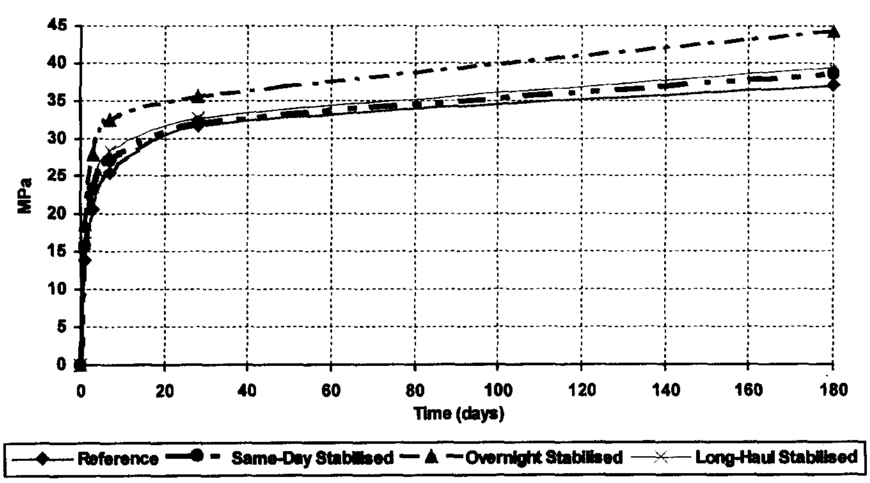

Fig. 6. Compressive strength — comparison between stabilized mixtures and reference mix.

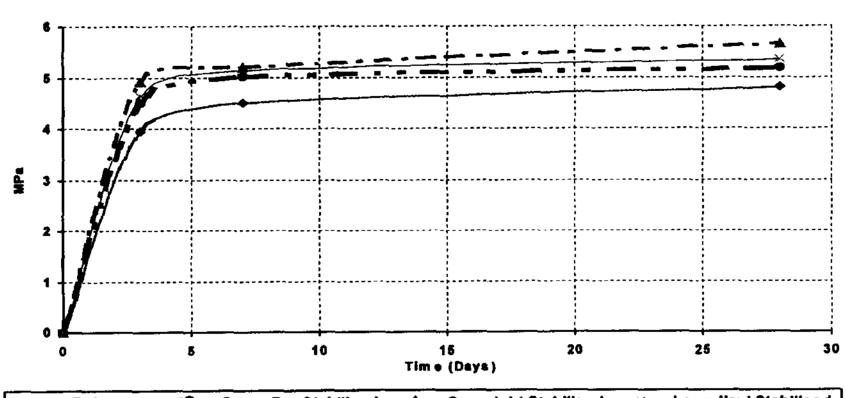

Fig. 7. Flexural strength — comparison between stabilized mixtures and reference mix.

within 0·01% of that of the reference mixtures. The overnight stabilized mixtures generally showed shrinkage equal to or slightly greater than 0·01% of that of the reference mixtures.

(e) The results of the chloride-ion penetration tests were somewhat variable but indicated that the stabilized and reference mixtures were of comparable quality with respect to chloride-ion penetrability.

(f) Proper air–void systems for protecting the concrete from frost damage were achieved in both the stabilized and reference mixtures, spacing factors were less than 200 μm for all mixtures.

(g) The setting times of reactivated concrete mixtures are quite comparable to those of the reference mixes.

The results of the tests performed at a nominal concrete temperature of 35°C indicate that, even at such temperature, the stabilizer can be used to produce same-day stabilized concrete which has fresh properties very comparable to those of the respective reference mixtures. Not only the fresh properties were comparable, but also the results of the tests performed on hardened concrete showed that:

(a) the compressive and flexural strengths of same-day stabilized mixtures produced at approximately 35°C were generally comparable to those of the reference mixtures;

(b) the frost resistance of the same-day stabilized mixtures manufactured at 35°C was greater than that of the reference mixtures;

(c) the drying shrinkage of the same-day stabilized mixtures produced at high temperature was approximately 0·01% greater than that of the respective reference mixes;

(d) the chloride-ion penetrability of the stabilized mixes manufactured at 35°C was comparable to that of the reference mixtures (Fig. 6 and Fig. 7).

For overnight stabilized mixtures, tests on fresh concrete were conducted on samples before the addition of the stabilizer (A) and on samples taken 18 h after the stabilizer addition and after new concrete has been batched onto the stabilized concrete (B). In the case of long-haul stabilized mixes, fresh concrete tests were performed on samples before (a) and immediately after (b) the addition of the stabilizer, and after the stabilized, fresh concrete was 3 h old (c) (Table 1).

The initial and final setting times of the same-day and overnight stabilized mixes were measured from the time that new concrete was batched on top of the aged, fresh concrete, while the setting times of the long-haul stabilized mixes were measured from the time concrete was initially batched.

As can also be seen in Table 1, the stabilizer has both water-reducing and air-entraining capabilities which should be considered during development of mixture proportions. The strength differences can be attributed to small variations in air contents, and in the water/cement ratio, and maybe to some favourable modification of the cement hydration reaction and paste microstructure.

USE OF EXTENDED SET-CONTROL ADMIXTURES IN MASS ROLLER COMPACTED CONCRETE (RCC)

RCC is 'concrete that, in its unhardened state, will support a roller while being compacted' (ACI 1994). Such a concrete therefore has a lower water content in the fresh state than conventional mass concrete, which is consolidated

Table 1. Basic properties of the fresh concrete mixes

Mix	*Slump (cm)*	*Unit weight (kg/m³)*	*Air content (%)*	*Initial setting*	*Final setting*
Reference	9·5	2280	6·1	4 h 5 min	5 h 42 min
Same-day stabilized	8·2	2310	5·8	4 h 20 min	6 h
Overnight stabilized (A)	9	2290	7		
Overnight stabilized (B)	9	2330	5·5	4 h 50 min	6 h 11 min
Long-haul stabilized (a)	9·5	2330	4·7		
Long-haul stabilized (b)	12·5	2290	6·1		
Long-haul stabilized (c)	7·5	2310	5·7	9 h 24 min	10 h 49 min

by means of internal vibration. Usually a 10 ton, steel drum, vibratory roller intended for compaction of asphalt or granular base is used to consolidate RCC.

The consolidation of RCC should be accomplished as soon as possible after it is spread, especially in hot weather, to ensure that the specified density is achieved throughout the lift thickness. The normal lift thickness ranges from 30 to 60 cm. Horizontal lift joints are inevitable in mass RCC because of the lift method of construction used to construct massive gravity sections. The USACE requires that lifts in mass RCC be constructed by spreading the RCC in approximately 15 cm thick layers until the desired lift thickness is achieved.

The lift joint preparation requires that the underlying RCC lift surface must be constantly maintained in a moist condition commencing immediately following consolidation. If necessary, the lift joint should also be cleaned prior to placement of the next lift. The design of RCC structures requires, in most cases, watertightness. Consequently, bonding between lifts must require the application of a bedding mortar over the active surface area between all lift placements. A bedding mortar is a high slump, high cement content mixture that is used to increase bond between lift joints, and to improve watertightness by filling any voids that may occur at the bottom of an RCC lift during placement and consolidation.

A separate concrete plant is typically required to produce the bedding mortar. Waterways Experiment Station investigated the possibility of using stabilized RCC sufficiently retarded to allow placement of a succeeding lift of RCC without extensive joint clean-up and the use of bedding mortar, affording a sensible saving in mass RCC construction.

The effects of stabilized RCC on joint bond strength were evaluated using direct-shear strength measurements, and compared with those bonded with bedding mortar. The results showed that with the use of the stabilizer, RCC can be retarded for prolonged periods of time and a water-reducing effect can be obtained. Results of direct shear tests on jointed specimens moulded in the laboratory indicated that shear strength could generally be improved if the lower layer could be maintained fresh. Also direct shear test results of jointed cores taken from real RCC test section showed an improvement in joint shear strength when the lower lift was maintained fresh using the stabilizer rather than allowing it to harden and then applying a bedding mortar.

USE OF EXTENDED-SET CONTROL ADMIXTURES IN SHOTCRETE

The use of stabilizer in shotcrete practice was first introduced in 1990 and is currently being used for rack stabilization in mines and tunnels and for other repair applications where shotcrete has been specified. This application resembles the long-haul application, with the exception that the stabilized shotcrete mixtures are activated at any time within the stabilization period by the use of proprietary accelerating admixtures that rapidly end the stabilization of the concrete, cause quick initial setting, and promote rapid early-strength development of the concrete after it is sprayed. The performance of such stabilized and activated shotcrete mixtures is similar to those of conventional shotcrete mixtures.

In conventional practice, the shotcrete mixtures are usually used within 1 h 30 min to 2 h after batching. Shotcrete applied within this time has plastic characteristics appropriate for use. The rule dictates that on a jobsite, shotcrete mixtures older than 90 min may be rejected because the pumpability, rebound, and bonding characteristics of the sprayed mixtures deteriorate after that time. Rejection of loads or clogging of equipment caused by shotcrete aged beyond the 90 min limit increases delays in the application of the shotcrete, requiring frequent equipment clean-out procedures that increase the waste of concrete and further complicate the placement of the concrete. For the shotcrete placed within the 90 min limit, consistency and rebound characteristics of the shotcrete mixtures deteriorate as they approach the end of their useful time limits, or potlife.

The use of extended-set control admixtures in shotcrete dry and wet is now a well-established practice in most European countries, in conjunction with the use of high-range water reducers and with the proprietary activator. The benefits of this technology in shotcreting can be summarized as follows:

(a) elimination or relaxation of the 90 min rule;
(b) extended useful lifetime of the plastic shotcrete mixture;

(c) reduction of rebound when the shotcrete is applied;
(d) consistent fresh characteristics during the potlife of the mixture;
(e) elimination of the need for on-site batching plants for shotcrete applications;
(f) reduction of waste and clean-up;
(g) reduced frequency or elimination of clean-out of pumps, when delays occur during the shotcrete activity during the day or between shifts.

CONCLUSIONS

A new chemical system useful for the reduction/elimination of waste concrete in the ready-mixed concrete plants has been presented. The system is composed of two chemicals, a 'Stabilizer' is used to stop the cement hydration and an 'Activator' to reactivate hydration.

The system is capable of controlling the cement hydration for up to 72 h, and can be used to stabilize returned plastic concrete overnight or over the weekend. It also allows fresh concrete to be transported over long distances (long time) before being placed without changing its rheological properties, or to stabilize overnight/weekend wash water in the truck drums that can be used the day after as mixing water for the freshly batched concrete.

Unlike common retarders, the stabilizer shows CSH nuclei formation when added with mix water, and it slows CSH and CH nuclei growth when added during or after the induction period. The addition of the stabilizer in concrete does not adversely affect any of the key properties of concrete either in the fresh or in the hardened state. Also the durability-related parameters are not negatively affected by the use of this hydration control chemical system.

Substantial improvements in terms of ease of work, reduction of wastes, cost savings and technical benefits can be obtained when using this system also in RCC applications and in dry or wet shotcreting.

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